Averaged potentials evoked from the brain during cognitive tasks, in the normal subject and in pathological states

Thesis

AVERAGED POTENTIALS EVOKED FROM THE BRAIN DURING COGNITIVE TASKS, IN THE NORMAL SUBJECT AND IN PATHOLOGICAL STATES

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A thesis presented for the degree of

Doctor of Philosophy

Department of Psychology,

The Open University.

November, 1985

Date of Submission: November 1985

Date of Award: 27.6.86

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The following parts of this thesis have been published:

The results of the right handed subjects (Experiment 1) appear in: Small, M. Asymmetrical evoked potentials in response to face stimuli. Cortex, 1983, 19: 441-450.

The results of the right handed subjects (Experiments 1 and 3) and the left handed controls (Experiment 2) have been reported in: Small, M. Hemispheric differences in the evoked potential to face stimuli. In: Aspects of Face Processing, (NATO ISI Series). Ellis, H.D., Jeeves, M.A., Newcombe, F. and Young, A.W. (Eds), Martinus Nijhoff, Dordrecht. (in press).

ACKNOWLEDGEMENTS

Most importantly I would like to thank Professor W.B. Matthews of the Department of Clinical Neurology for the use of the equipment and for allowing me to examine his patients. I also greatly appreciate his helpful advice and prompt critiques of chapters during the write-up.

I also wish to thank Dr. Martin LeVoi of the Department of Psychology, Open University, for his useful criticism and advice, and in particular for his help with the statistics and for use of the Open University Vax computer.

I am also indebted to Dr. Freda Newcombe of the Department of Neuropsychology, Oxford, for enabling me to examine the prosopagnosic patient and the group of missile injured men, and for the loan and inclusion of their extensive case histories. Mrs Joan Smith deserves credit for efficiently organising their admissions.

And of course .....

David Small
Tim Robinson
Steve Thomas
Les Aylesbury
Trevor Fayers
John Thornton
Richard Willsden
Carole Cockman
Nicki Leverett
Jenny Rack
Diane Leverett
Jean McKelvie
Stella Joshua
Bea Carlyle
Erika Pountney
Clare Smith
Barbara Williams
Christina Crawford
Rosemary Sprigg
Julie Doggart

to who my special thanks are due for giving up their time and volunteering as subjects.

ABSTRACT

Investigation of patients with cerebral lesions and tachistoscopic studies in both normal subjects and commissurectomised patients has shown that the right hemisphere has a distinctive role in the processing of faces. The initial aim of this study was to assess whether these indications of cerebral asymmetry, found with traditional methods, could be mirrored by electrophysiological techniques. Such an approach would help to define not only lateralisation of non-verbal processing but also localisation of function within a hemisphere.

Normal, right handed subjects (assumed to be left hemisphere dominant for language) were presented with four visual conditions: slides of known and unknown faces in order to observe any effect of recognition and two non-verbal control series which provided (i) a complex stimulus other than a face and (ii) a physical stimulus without cognitive content. Both P100 and P300 of the visual evoked response were recorded during all conditions. The similar mean amplitude and latency values obtained across subjects proved the technique to be capable of producing replicable and consistent results although minor changes were apparent in relation to the subjects' sex and age. The dissimilar topographies of P100 and P300 implied different origins for these two components, within the occipital cortex and association areas respectively.

The amplitude of P300 was larger over the right than the left hemisphere in response to all types of stimuli. However, this emphasis was significantly greater over the right side ($p < 0.001$) with face slides than during the control conditions, inferring that the asymmetry was associated with facial factors rather than stimulus complexity. Absence of this right sided superiority from the same group of subjects in

response to inverted face slides strongly suggested that the asymmetry was specific to vertical orientation, i.e. upright faces. The fact that there was no difference between the response to known and unknown faces showed that the right sided P300 superiority occurred without relation to aspects of facial memory; it was present regardless of whether or not a face had been veiwed before.

With left handed normal subjects, assumed to be less lateralised for non verbal processing, the right hemisphere P300 amplitude emphasis was not apparent suggesting that the asymmetry previously recorded in dextrals represented organisation of cerebral function.

Investigation of language lateralisation, using this evoked potential technique, was also carried out in right handed subjects. In response to slides of words there was no converse (left greater than right) P300 amplitude asymmetry except for an increase over the left temporal region in females. Word stimuli, unlike non-verbal material, showed P300 to be of equal amplitude at all electrode sites which, together with the absence of an asymmetry, implied that either verbal processing takes place in structures inaccessible to surface recording or that such function is not so clearly localised.

The opportunity was also taken to investigate patients with cerebral dysfunction in order to observe any associated alteration in waveform. They were presented with the same types of stimuli described above. The findings in a patient with prosopagnosia suggested the presence of bilateral cortical damage at an early stage in visual processing and his dissociation of P100 latency across conditions also implied that stimulus specificity may occur in man at an early perceptual level. The results from the final experiment, which involved patients

with missile injuries to the brain, similarly provided evidence of stimulus specificity. Furthermore, men from this group with right sided wounds showed variations in P100 latency depending on the type of stimulus, providing evidence of functional differentiation within the right hemisphere at an early stage in visual processing.

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CHAPTER 1

INTRODUCTION PART 1.

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It has been realised for many years that the left and right cerebral hemispheres of man are not functionally equivalent although they share a close identity in structure. During the early 1860's the observations of Dax and Broca on right handed patients with unilateral brain disease first pointed to a major role of the left hemisphere in the processing of speech and evidence of cerebral lateralisation of language is now firmly accepted. Despite this, there has been an unwillingness to admit that the other hemisphere, often termed the "minor" or non-dominant, might also have areas of specialization in which it excelled and it was not until the time of World War II that a series of careful studies on patients with well-lateralised brain lesions began to reveal the full importance of the right hemisphere. Since then, the possibility of complementary specialisation has been explored more fully and several converging lines of enquiry have shown that the right hemisphere does indeed have a distinctive function in non verbal, visio-spatial tasks including the recognition of faces.

Among the ways of investigating hemispheric specialisation, the most established is that of analysing the effects of unilateral, circumscribed lesions. This method retains certain advantages for it allows one to examine the question of hemispheric difference in detail by observing the form of functional impairment produced by asymmetrical damage to particular cortical areas. Such clinical evidence indicates that left hemisphere lesions disrupt verbal abilities, leading in general to various forms of aphasia, whereas right sided lesions interfere with the apprehension of complex configurational properties of visual stimuli, including an impairment in the ability to recognise faces.

During the 1960's this evidence has been strengthened and extended

by observations on patients with midline cerebral commissurectomy. This operation, which eliminates direct cross-communication between the hemispheres, leaves both sides intact but functionally independent. In patients who have had such surgery, each hemisphere can be tested separately for its positive as well as its negative competence, and direct comparisons can be made between the independent performance of the left and right hemisphere in the same individual. The results conform with the previous findings in that if linguistic processing is involved, the subject's response is dominated by the left hemisphere, but with the perception of faces and complex patterns the right hemisphere is superior.

Evidence also comes from studies on patients with a rare defect termed prosopagnosia, which is an inability to recognise familiar faces such as friends and relatives. A good deal of attention has been directed to the location of lesion sites in these patients, including detailed reports of the clinical manifestations and descriptions of more direct (post-mortem) findings. Although the picture is by no means straightforward, the right hemisphere does appear to be implicated more than the left.

It is obviously convenient to similarly study cerebral asymmetries in normal, intact subjects, and such experiments have given valuable corroboration to the conclusions drawn from the clinical material. This conformation is particularly important because the results from commissurectomies are based on patients who usually have a history of early brain damage and who consequently could have an abnormal distribution of function between the two hemispheres. In normals, attention has been directed to laterality effects in visual perception and certain right/left differences to lateralised visual stimuli have been reported, including a superiority of the left visual field (subser-

ving the right hemisphere) to face stimuli.

This evidence for a right hemisphere superiority in the processing of faces based on lesion studies, the striking effects of commissure section, the prosopagnosic syndrome and the demonstration of functional asymmetry in normal subjects, will now be reviewed in more detail.

Lesion studies

A considerable literature has built up in recent years dealing with visual perception in patients with cerebral lesions. In order to evaluate the results of such studies it would perhaps be helpful to consider the types of test which have been used to study facial discrimination in these patients. They have been of three broad types:

1. Matching procedures in which a facial photograph has to be matched to another photograph of the same face. Some tests require matching of photographs taken from different angles or modified by various expressions.

2. Those testing immediate recall of previously unfamiliar faces. The subject might be shown a facial photograph which is subsequently removed, and he or she is then required immediately to pick out the face from a display of several faces.

3. Those testing more long-term visual memory for faces, such as the recognition of well known public figures or of previously unknown faces after an appropriate delay. This type of test is the most closely related to the clinical symptom of prosopagnosia.

Benton and Van Allen (1968) have investigated facial recognition in patients with lesions confined either to the right or left hemisphere by using a matching procedure, which made no demands upon immediate memory.

The task presented to the subject involved matching identical photographs of an unfamiliar face and similarly matching different photographs of the same face. They found that the mean performance level of the patients with right hemisphere lesions was significantly inferior to that of patients with left hemisphere lesions. Grossly defective performances were made mainly by the patients with right sided lesions. The results were not related to the presence of visual field defect, the presence of aphasia or the type of lesion. These observations indicate that impairment in facial recognition is closely associated with disease of the right hemisphere. No locus effect could be detected with that patient group nor were there any explicit criteria for localised lesions.

Milner (1968) describes a series of experiments involving facial recognition specifically designed to contrast the effects of equivalent right and left anterior temporal lobe excisions. Groups of patients with cortical resections from right and left temporal, frontal or parietal regions were required to recognise photographs of unfamiliar faces from a larger array, having been shown the photographs previously. Three variations of the task were used: (a) the interval of two minutes between the initial presentation and the recognition test was filled with an irrelevant task, (b) the interval remained the same but the interpolated task was omitted and (c) there was no delay between presentation and retest. On the first two tasks the patients with right temporal lobectomies showed marked deficits compared with all the other groups. The right temporal lobe patients with extensive hippocampal removal were found to be significantly more impaired relative to the right temporal subgroup in whom the hippocampus had been spared. These results appeared to indicate that the patients with right temporal lobe excisions were forgetting the initial set of faces more rapidly than the other subjects.

However, on the third task ("immediate recognition") no obvious group differences were seen because the normal controls and the other patients did worse than with the delay. Only the right temporal group showed no significant difference between the two conditions (with and without an interval).

These differential effects of right and left temporal lobe resections on memory for faces are all the more convincing because the groups whose performance was compared were well matched with regard to age, general intelligence, aetiology of preoperative lesion, seizure history and the extent of tissue removed. Furthermore, the results cannot be explained away by reference to visual field changes for the right and left temporal groups did not differ in this respect.

Milner points out that the breakdown of performance on the facial recognition test in the right temporal group could have arisen as a consequence either of poor initial perception, poor retention, or both. Patients with right temporal lobe damage are also reported to perform less well with discrimination of recurring nonsense figures (Kimura, 1963). Milner therefore stresses that the decrement found with facial recognition could reflect a general impairment for non-verbal patterned stimuli and not faces per se.

In a study by Yin (1970) these two separate problems, that of intra-hemispheric locus of lesion and the type of visual stimulus, have been investigated more extensively. Basically, if certain injuries selectively impair facial, but not object recognition (and vice versa) there would be some reason to believe that the former is a special ability (see the double dissociation mentioned by Warrington and James, 1967). The subjects comprised fifty-six American Army or Navy personnel with open

or closed head injuries incurred in the Korean conflict. The thirty-seven patients with penetrating missile wounds were divided into five categories, those who had received right frontal, left frontal, right posterior, left post-erior or bilateral injuries. These individual groups were compared with nineteen closed head injury patients and with twelve normal controls (who had served unscathed in the same military units as the injured men).

Each subject viewed an inspection series of 40 photographs, 20 unfamiliar male faces and 20 houses. The subsequent test series consisted of 12 pairs of faces and 12 pairs of houses, each pair containing an exact duplicate of a picture seen in the inspection series and one not previously shown. For each pair the patient had merely to indicate which picture he had seen before. All patients and control subjects were tested for recognition memory with both the faces and houses in upright and inverted orientations.

The results showed that compared to the other patients and controls, the right posterior group performed significantly less well on upright faces, yet there was no significant difference between the groups on upright houses. In contrast, the right posterior patients performed better than the other unilaterally injured groups on the inverted face test. This dissociation of performance on upright and inverted face recognition, between the patients with right posterior injuries and all the other unilateral injuries, suggests that the right posterior patients had a deficit specific to normally presented, i.e. upright, faces. Since these patients did worse than the others when the faces were upright, but better when they were inverted, the results are difficult to attribute to variations between patient groups, such as age, intelligence and size of

lesion. Yin concludes from this study that there may be a special face-specific recognition system located in the right hemisphere which is sensitive to orientation. Although he does not say so, a further conclusion could be that the recognition of inverted faces is not specifically carried out in the right hemisphere.

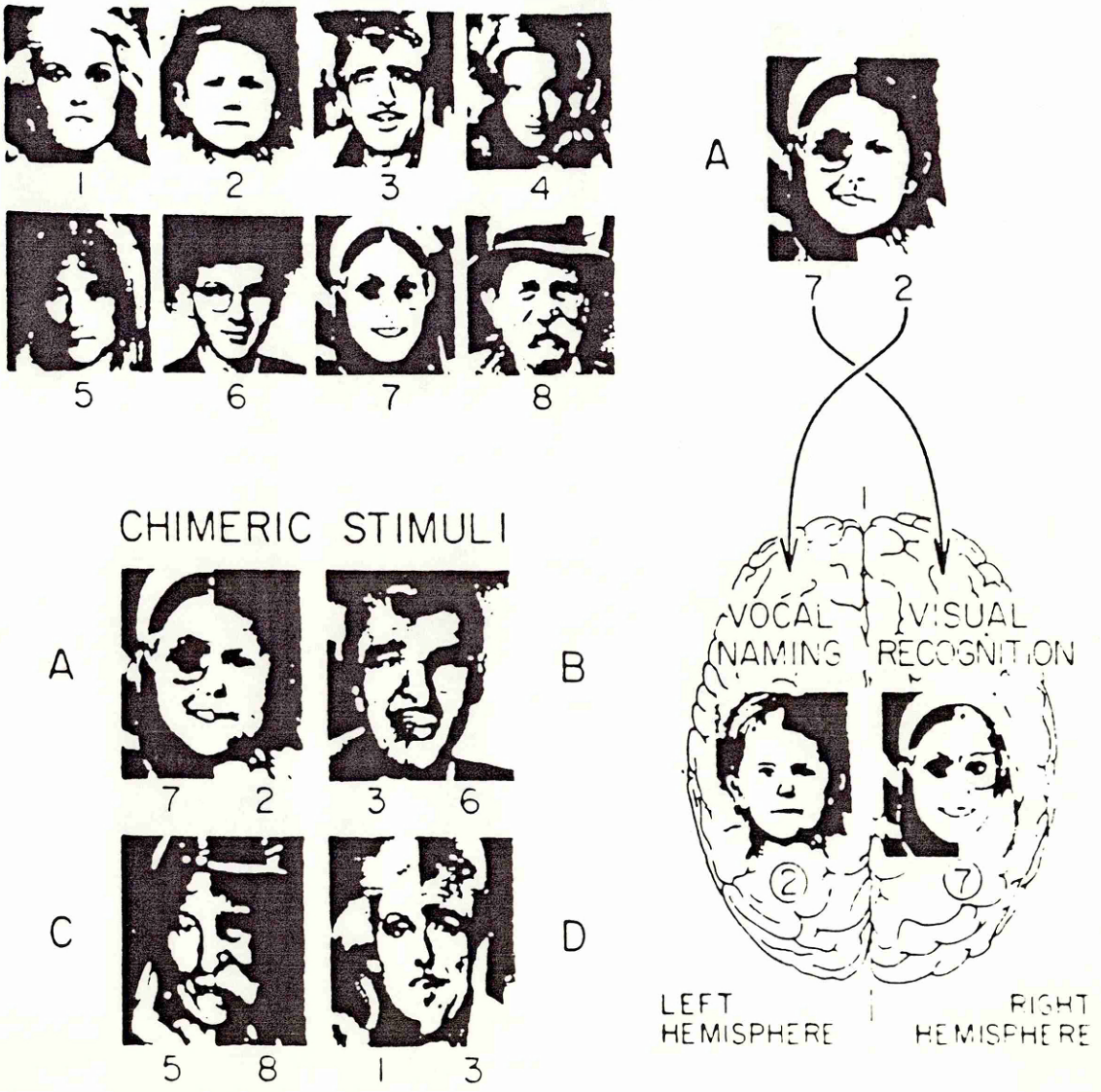
Faulty recognition of faces does therefore seem to be strongly associated with right sided lesions though the acceptance of the posterior region of the right hemisphere as the most important site for this impairment is questioned by the findings of Benton and Van Allen (1968), because perfomance level on their test of identification of unfamiliar faces was not related to the intrahemispheric locus of lesion.

Commissurectomies

Recognition of familiar faces cannot though be the exclusive province of the right hemisphere for facial agnosia does not occur after right hemispherectomy (Damasio, Lima and Damasio, 1975). Similarly, commisurectomized patients can recognise faces presented to either the right or left visual field, that is, with either the isolated left or right hemisphere. However, the results of a detailed study by Levy, Trevarthen and Sperry (1972) of four patients who had undergone surgical section of the entire corpus callosum, and forebrain and anterior commissures provide clear evidence for a functional superiority of the right hemisphere for facial recognition. The experiment employed tachistoscopic presentation to the separate half fields of vision corresponding to each cerebral hemisphere. According to the pattern of retinocerebral connections, stimuli lying in the left part of the visual field (that is, to the left of the fixation point) are projected to the right halves of the retinae and to the right hemisphere whereas stimuli lying in the

right part of the visual field (that is, to the right of the fixation point) are projected to the left halves of the retinae and to the left hemisphere. A superiority of perception (as measured by speed or accuracy) in one field compared with the other argues for a special "dominance" of that particular hemisphere.

Fig 1:1

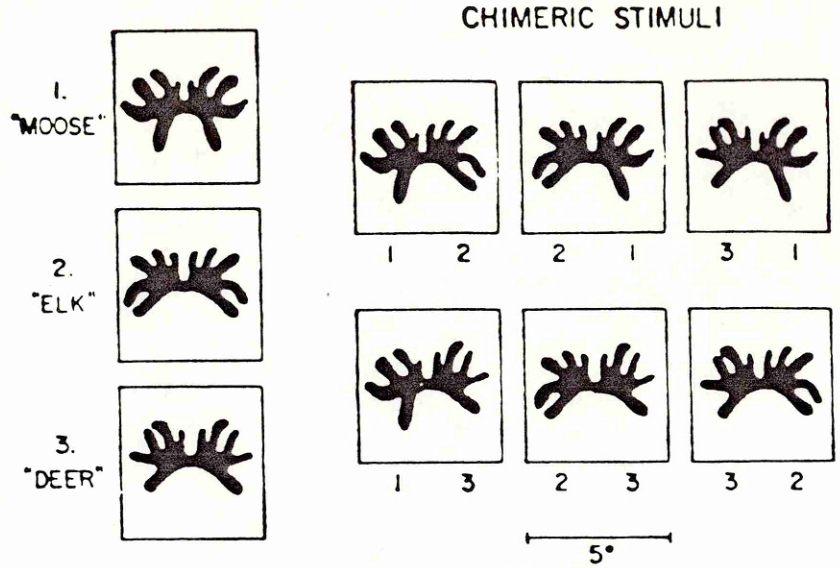


The patients were instructed to view a chimeric stimulus (ie the left half of one face joined at the midline to the right half of another face, (Fig 1:1) projected via a tachistoscope to the dominant eye,

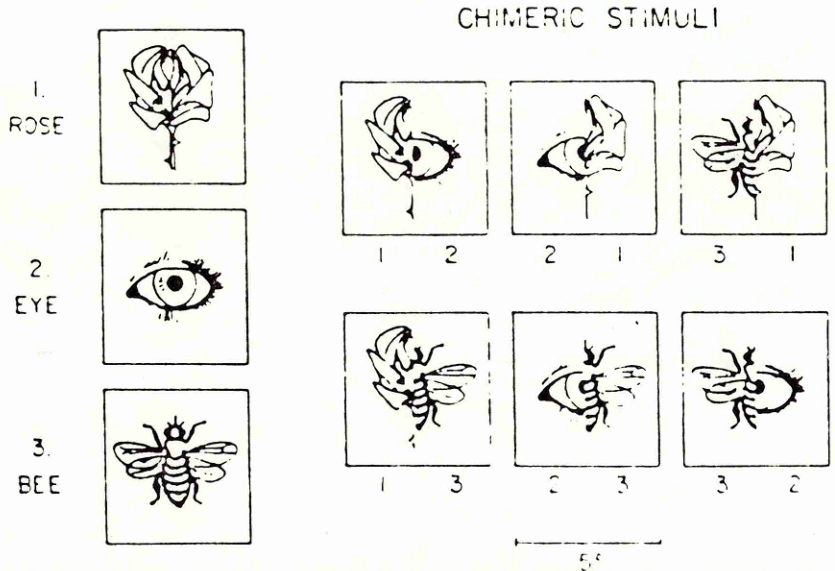
subtending an angle of 5 degrees centred on the fixation point. Original, whole faces were presented first in free vision on a table in front of the subject who was then requested to choose the face he subsequently saw flashed in the tachistoscope either by (a) pointing with the right hand, (b) pointing with the left hand or (c) by naming the face. The design of the test depended on the phenomenon of "hallucinated completions", that is the fact that commissurectomy patients, when confronted with a stimulus which extends across the midline of the visual field, will report seeing a whole and complete picture even though each hemisphere only receives that part of the stimulus which is in the contralateral visual field. This method of presentation therefore induces separate and rival perceptual processes in the isolated right and left hemispheres. When responding with the left hand all subjects showed a strong preference for the face presented in the left visual field (the one appearing on the left side of the chimeric figure which projected to the right hemisphere). 89% of responses corresponded to the face in the left half field and 10% to that shown in the right half field. Even when the right hand was used for pointing, this strong asymmetry remained, 75% for the left half field and 20% for the right half field. However, when the response required verbal naming, the scores reversed in favour of the right half field of the chimeric stimulus, (36% left half field and 49% right half field).

Whilst the important finding of this study is the very clear left half field superiority for faces, it is interesting that patients did occasionally point to the stimulus shown in the right half field. Possible interpretations for these exceptional responses include cross cuing or use of mid-brain mechanisms.

Figs 1:2 and 1:3



Perception of unfamiliar forms.



Recognition of familiar objects.

The same patients were also tested with two other sets of stimuli in order to establish whether the right hemisphere superiority for faces was specific or representational of a more general capacity for

processing complex spatial forms. One set consisted of "antler" patterns (Fig 1:2) which comprised stimuli which had properties such as bisymmetry and complex organisation, in common with faces, but at the same time were unfamiliar, not face-like and not readily distinguished by name. The second set was made up of chimeric familiar objects (Fig 1:3) in order to find out if the same minor hemisphere superiority would occur with common objects with well known and long established verbal labels. On both of these tests the results were similar to those obtained for faces, i.e. a strong left field preference occurred in the trials involving selection by manual pointing with either the right or left hand.

Levy et al concluded that the right, minor hemisphere in these patients dominated the response when no language was involved and only a direct manual reaction was required, such as pointing. It is of special interest that the right hemisphere was still superior even when the major, left hemisphere was favoured by requiring the subjects to use their right hands. While the results of the "antler" and chimeric familiar object tests also showed a minor hemisphere superiority in both cases, the authors stress that the data in no way exclude the possibility that face recognition is a special ability beyond that for general, complex visual processing.

Prosopagnosia

More pertinent to the present discussion is the investigation of those patients in whom recognising familiar people, for example relatives and friends, proves particularly difficult. A rare syndrome which involves being unable, on the basis of facial cues alone, to recognise a highly familiar person has been known ever since a case was first reported by Charcot (1887). Bodamer (1947) labelled this deficit

"prosopagnosia" because he believed that a face-specific process, more primitive than that used for recognising other objects, had been disrupted. However, there is still some disagreement as to the exact nature of the deficit in these cases. Supporting the theory that prosopagnosia is in fact a separate entity, (i.e. a purely facial agnosia), Tzavaras, Hecaen and Le Bras (1970) report a lack of correlation between poor performance on tests of facial recognition and a range of other tests of a complex perceptual nature. Many researchers though regard the disorder as merely one form of disturbance in the visual recognition process. De Renzi, Faglioni and Spinnler (1968) describe a patient with severe prosopagnosia who was also impaired on tasks requiring the discrimination of complex visual patterns. Beyn and Knyazera (1962), in a report on one prosopagnosic, found that the patient was also unable to identify familiar rooms, buildings, streets and places although spatial perception as such was not disturbed. The patient could distinguish between different types of buildings shown in pictures but was unable to recognise actual buildings or places which had previously been familiar to him. The authors suggest that prosopagnosia does not merely represent a generic failure of object recognition but reflects a specific incapacity to react to the unique characteristics of particular objects, such as faces, buildings and places. Generic recognition may be intact but individual recognition grossly impaired.

That such patients do experience problems in the recognition of other familiar stimuli (apart from human faces) has also been reported by Bornstein, Sroka and Munitz (1969), who describe a farmer no longer able to recognise his cows even though he had been reared on a farm and had previously an outstanding ability to identify animal faces. Similarly, Damasio, Damasio and Van Hoesen (1982), in their investigation of three

prosopagnosic patients, found that they had become unable to recognise their cars and articles of clothing. Two of these prosopagnosic patients were given a task devised to assess the contributions of both object specificity and the ambiguity of a category. The task consisted of recognising and naming sets of visual stimuli belonging to several groups, for example (i) animals (which contained close-up photographs of a robin, domestic cat, horse etc), (ii) motor vehicles and (iii) abstract symbols (e.g. question mark, percentage sign, swastika and exclamation mark). While stimuli such as an owl, elephant and horse were always correctly named there were mistaken identity responses regarding the three different but visually similar domestic cats, which were recognised as "tiger", "cat" and "panther". The patient's difficulty occurred when the stimulus belonged to a visually ambiguous category (a group of stimuli in which numerous different members are structurally similar) rather than being in itself visually distinctive (i.e. when different members adopt different structures). Like Beyn and Knyazera (1962), Damasio et al conclude that prosopagnosia is related to "the need to evoke the specific context of a visual stimulus belonging to a visually ambiguous category". In other words, the generic class to which a stimulus belongs presents no difficulty, but recognition of an individual member of that class, whose identity had previously been learned, is impaired. Patients with prosopagnosia know that a face is a face and name it as such, yet they are unable to recognise a given familiar face; they do not know to whom it belongs and are consequently unable to name it. Demasio et al conclude that the impairment lies in the contextual association needed to determine the history of an object in relation to the subject. The matter, however, is still controversial for more recently De Renzi (1985)

has described three patients with prosopagnosia lasting more than one year who were quite able to identify their personal belongings (ties, razors, wallets etc) and their own handwriting from similar arrays. They could also distinguish different types of fruit (lemon, orange), playing cards, coins and banknotes. De Renzi therefore argues that the prosopagnosic impairment is not simply a failure to identify one exemplar of a category but is a deficit specific for face memory.

A number of studies have shown that with prosopagnosia, the disability which underlies the recognition of a familiar face is not apparent when discriminating unfamiliar faces. Assal (1969) describes a 57 year old man, who, following removal of a large intracerebral hematoma in the right parieto-occipital area, could only recognise his relatives if they had spoken to him. Physicians and nurses were recognised when they were in uniform but not in civilian clothes and photographs of celebrities posed great difficulty. However, when given a battery of tests in which he had to match unfamiliar faces, his performance was well within normal limits. Tzavaras et al (1970) report similar findings in a 61 year old male with facial agnosia, a superior altitudinal hemianopia, spatial disorientation and impaired colour vision, suggesting the presence of a bilateral lesion following a cerebrovascular accident sixteen years previously. Although the patient had great difficulty recognising familiar people including his wife, his performance when discriminating unfamiliar faces was almost equivalent to the mean score obtained from control subjects.

Benton and Van Allen (1972), in a detailed study of a young female prosopagnosic, have also shown that these two tasks are dissociable. While unable to recognise her husband and children, the patient performed well within the limits of normal variation on a test requiring the

matching of unfamiliar faces. Benton and Van Allen conclude that prosopagnosia cannot be explained solely in terms of a general visio-perceptive impairment and suggest that the primary defect may be of an associative nature involving impairment of current with past experience.

These studies show that the prosopagnosic defect is remarkably similar in the majority of reported cases but seldom presents as an isolated form and almost always has varying associated defects such as colour agnosia, a spatial disorder and visual object agnosia. The latter seems to reflect a defect in individual recognition, an impairment in the discrimination of stimuli which are structurally very similar. Recognition of familiar and unfamiliar faces in these patients is often dissociable suggesting that their difficulty may lie in an inability to associate present with past experiences.

One of the outstanding questions of this condition is whether a purely unilateral cerebral lesion can be responsible or whether bilateral lesions are necessary. In the majority of published cases investigations have been scanty and analysis of the reported clinical details is frequently unrewarding from the viewpoint of precise localisation. However, a number of studies have made certain observations about the localisation of the lesions from the available clinical evidence and in a few cases, radiological or operative findings have been described. Beyn and Knyazera (1962) conclude that the sudden onset of prosopagnosia, colour agnosia, bilateral field defects (a right homonymous hemianopia and a left superior quadrantic field defect) and an impairment in spatial orientation, in a 39 year old male patient, are consistent with a bilateral occipital lobe lesion due to cerebrovascular disease. Cole and Perez-Cruet (1964) suggest that bilateral upper altitudinal field

defects, constructional apraxia, difficulty with colours and topographical agnosia together with prosopagnosia, in a 38 year old male, lend support for a bilateral parieto-occipital lesion. Bornstein, Sroka and Munitz (1969), describing the sudden onset of prosopagnosia with animal face agnosia in a 58 year old farmer, report that although there was no impairment in topographical orientation or colour vision there were accompaning left sided brisk reflexes and a dense, left homonymous hemianopia, reflecting unilateral damage in the right hemisphere.

Localisation of lesions by CT scans has been reported in three prosopagnosic patients by Whiteley and Warrington (1977). Bilateral occipital lobe infarctions, left larger than right, were found in a 65 year old male whose inability to recognise familiar people was accompanied by disturbed colour vision, mild left hemiparesis and bilateral visual field defects (enlarged blind spot on the right and a peripheral nasal defect on the left). There was no topographical confusion or dressing apraxia. Case 2, a 55 year old female, presented with sudden onset of an inability to recognise faces. She had no difficulty finding her whereabouts or in dressing, and testing of colour vision on the Ishihara chart was normal. Clinical examination revealed a mild left hemiparesis and a left homonomous hemianopia with an upper temporal scotoma in the left eye. The CT scan showed a density consistent with a haematoma in the lateral part of the right occipital lobe. The left hemisphere was normal.

Case 3, a right handed, 49 year old female, was admitted following increasing occipital headache with blurring of vision on the left side. A dense left homonymous hemianopia was present but otherwise neurological examination was normal and no difficulty in facial recognition was noted. CT scan showed a tumour in the medial portion of the right parieto-

occipital region with a shift of midline structures to the left, but otherwise the left hemisphere was normal. A right occipital craniotomy revealed an astrocytoma on the medial surface of the occipital lobe and occipital lobectomy was performed. Visible tumour, deep in the parietal lobe was also removed but no tumour was seen in the left hemisphere. After regaining consciousness, the patient was unable to recognise anyone from their facial appearance. She had a left homonymous hemianopia but no other neurological signs. The tumour site was irradiated and two months later, at follow-up her symptoms had largely resolved. This recovery raises the possibility that the critical area for facial recognition was not ablated but merely disturbed by the surgical procedure, implicating the region anterior to the occipital lobe itself.

Although the first case described in this report was shown, radiologically, to have bilateral occipital lesions, the other two patients, on the evidence available, appeared to have purely unilateral, right sided lesions. De Renzi (1985) also reports two prosopagnosic patients who were shown, by CT scan, to have lesions confined to the right hemisphere. Both patients had softening confined to the territory of distribution of the right posterior cerebral artery without any sign of abnormality in the left hemisphere. So, to summarise, it is clear that some clinical reports provide evidence of bilateral disease (shown usually by bilateral field defects) but there is also evidence to suggest only right hemisphere involvement.

Some workers argue that clinical findings alone are insufficient for the purpose of accurate localisation (Bornstein and Kidron, 1959; Gloning et al, 1970) but in only a small number of cases have there been detailed reports of necropsies. Meadows (1974) has analysed the clinical

case reports and reevaluated the pathological findings in the only detailed reports of necropsies on prosopagnosic patients, which total seven. In all cases there was right occipitotemporal pathology with evidence of bilateral disease. In five cases the left hemisphere lesion was symmetrically sited, i.e. in the left occipitotemporal area, but in the remaining two patients the left sided lesion consisted only of mild gliosis in the angular gyrus region (described by Pevzner et al, 1962) and invasion by tumour through the posterior part of the corpus callosum, but only as far as the ventricular wall, (Hecaen et al, 1957). Meadows' review of the visual field defects found in forty-two cases of prosopagnosia (published since 1930) also failed to support the consistent presence of symmetrical lesions, for right upper quadrantic field defects were not a regular finding. Although visual field defects were nearly always present, in approximately half of the cases (23 patients) there was no right visual field defect at all. In unilateral cases the defect was usually on the left, most frequently a left upper quadrant involvement, suggesting a low, posteriorly placed lesion in the right cerebral hemisphere. There were, however, four cases with unilateral right sided defects and four patients without visual defects.

This evidence points clearly to the importance of occipitotemporal lesions in prosopagnosia, particularly those within the right hemisphere. Lesions in this area were found in all seven necropsy cases and this correlates with the extremely high incidence of left upper quadrantic visual field defects in the clinical case reports. However, left hemisphere lesions were also present in the seven necropsies but only five of these were occipitotemporal as in the right hemisphere. Meadows therefore concludes, rather cautiously, "that bilateral occipitotemporal lesions may underlie many cases of prosopagnosia, but that in some cases,

the right occipitotemporal lesion is not accompanied by a correspondingly sited lesion in the left hemisphere".

Damasio, Damasio and Van Hoesen (1982) have similarly reviewed the ten postmortem reports of prosopagnosia published between 1892 and 1982, which include the same seven cases described by Meadows. They also report the CT scan results from three of their own patients with prosopagnosia. Their analysis of the postmortem data showed that in all cases the lesions were not only bilateral but functionally symmetrical. There was only one exception, the case described by Pevzner et al (1962). The conclusion by Damasio et al is therefore almost identical to that of Meadows, the only difference being the interpretation of the left hemisphere pathology in the patient reported by Hecaen and Angelergues (1962). The lesions in all three patients who underwent CT scans were bilateral and symmetrically located in the mesial occipitotemporal regions, the larger lesion being always on the left.

Certainly, evidence of bilateral damage conveniently accounts for the rarity of this condition but the inconsistent location of the lesion in the left hemisphere (reported by Meadows) and the fact that the clinical evidence often implicates the right hemisphere more than the left still need to be explained. Meadows puts forward several possibilities to overcome these anomalies. He suggests that some patients with clinical evidence of only unilateral disease may indeed have only a unilateral lesion and be rare individuals in whom function of facial recognition is unusually localised in the right hemisphere, whereas in most individuals bilateral lesions are required to cause prosopagnosia. Another possibility is that a combination of lesions in bilateral cases has the same effect as a strategically placed, single right sided lesion.

For example, recognition of familiar faces might depend on connections from both occipital cortices to the right occipitotemporal cortex. Lesions causing destruction of the right primary visual cortex in combination with destruction at some point along the pathway from the left striate cortex might have the same effect as a single, right occipitotemporal lesion. Meadows also suggests that a particularly discrete right occipitotemporal lesion might "inhibit" or "suppress" any contribution made by the left hemisphere towards facial recognition. It is known that the left hemisphere can identify faces when disconnected from the right hemisphere (Levy et al, 1972). With a larger right sided lesion, this inhibitory effect might be more deranged allowing total identification of faces by the left hemisphere. This proposal accounts not only for the rarity of prosopagnosia, but also for the retention of facial recognition in patients with large right hemisphere lesions such as right posterior cerebral artery occlusion and right hemispherectomy.

Functional asymmetry in normal subjects

The typical experiment in this field employs visual stimuli presented tachistoscopically to the separate half fields of vision (corresponding to each cerebral hemisphere), as described earlier in the method used to test commissurectomised patients. Gross dissociation of hemispheres is obviously not the case in the normal subject, for visual information which is selectively channelled into one hemisphere is also made available to the opposite side by the forebrain commissures. Because this callosal transmission takes time, it follows that a measurable interval must intervene between the arrival of visual information to the directly stimulated side and the reception of this corresponding information by the other hemisphere. A logical hypothesis would predict that if

a subject is asked to produce, as quickly as possible, a discriminative response to a visual pattern presented in one hemifield, the responses will be faster to a stimulus presented in the half field projecting directly to the hemisphere specialised in processing that particular visual configuration, than to a stimulus presented in the other half field, which has to cross from the non-specialised hemisphere to the other side of the brain for analysis.

Rizzolatti, Umilta and Berlucchi (1971) submitted this hypothesis to experimentation in a study in which two groups of right handed subjects were tested for choice reaction time to lateralised presentations of single capital letters and photographs of unknown faces respectively. Each stimulus was presented monocularly for 100 ms, 5 degrees to the right or left and on a level with the fixation point. The task was to press a key as quickly as possible following the appearance of a positive stimulus (e.g. a face that had been arbitrarily selected as an "attend to" stimulus which subjects had previously learnt to recognise) and not to press a key following a negative one. The type of presentation and response was varied to include the four possible combinations, e.g. right field - right hand, right field - left hand, left field - right hand and left field - left hand. In each block (faces or letters) positive and negative stimuli were presented in quasi-random sequence, and the order of the four experimental conditions was varied over sessions. The results showed a highly significant reaction time superiority of the right visual field, projecting to the left hemisphere, when the stimulus was a letter (18.5 ms faster than the left visual field) and a reaction time superiority of the left visual field, projecting to the right hemisphere, when the stimulus was a face (14.5 ms faster than the right visual field).

Kinsbourne (1970 & 1972) has argued that laterality effects in perception can be attributed to an attentional bias including an ocular deviation towards the visual field contalateral to the activated hemisphere, rather than to more efficient transmission of information along the shorter pathway to this hemisphere. Accordingly, the results of Rizzolatti et al (1971) could be explained by selective attention and an uncontrolled shift in gaze towards the respective visual field in the letter and face blocks. However, Berlucchi (1975) points out that the superiority in choice reaction time of the right visual field for letters and the left field for faces could still be observed when these two types of lateralised stimuli were presented intermixed in a random sequence to the same subject in the same experiment. Since on no trial did the subject know what kind of stimulus was going to appear, the difference in reaction time between visual fields could not be the result of hemispheric preactivation due to prior knowledge of the stimulus. Instead, the differences must have been, at least in part, caused by information transfer between the direct and commissural inputs.

It should be noted that a later investigation into hemispheric organisation and sex differences by Rizzolatti and Buchtel (1977), using an identical testing procedure as in the study just described, could not replicate in females the left visual field superiority to faces previously found in males. However, Gilbert (1977), using the same method and the same type of unknown face discrimination task, found a significant, left field superiority (in speed of response) in both male and female subjects, with no difference between the two groups.

Geffen, Bradshaw and Wallace (1971), also measuring response times, have similarly reported a left visual field advantage to face stimuli but

by using a slightly different procedure. Each subject was asked to memorise one Identikit face, which was subsequently presented tachistoscopically in the centre of the visual field. Superimposed on this "memory" face was a small central cross for fixation. A test face was then presented for 160 ms, either in the right or left field and the subject's task was to judge whether this face was the same as or different from the memorised one. Onset of the test face triggered an electronic timer which stopped when the subject pressed one of two response buttons, (same or different). An analysis of the reaction times showed that test faces presented in the left visual field were responded to more rapidly than those in the right visual field, with no significant difference between right and left hands in speed of response.

While these studies provide evidence of a more rapid overall rate of facial processing by the right hemisphere compared to the left, there is also information available concerning the level of recognition accuracy when faces are presented to only one hemisphere. Hillyard (1973) tested right handed subjects using tachistoscopic presentation of unknown faces, again requiring a same/different judgement. The subject's task on each trial was to state whether a face appearing in a brief, initial exposure (40-60 ms) was the same as a comparison one, presented for 3 seconds, which followed. Comparative accuracy of facial recognition in the left visual field was significantly better than that in the right visual field. In order to investigate whether an effect of memory for non-verbal visual stimuli could be demonstrated by the right hemisphere, the subjects were also tested for recognition accuracy with a 10 second delay between the test and comparison exposures. It was hypothesised that any laterality effect for face stimuli would be enhanced by this interval if the right hemisphere contained such a memory mechanism. The results

however showed no demonstrably significant difference in the visual field effect for the two retention intervals, with or without a delay.

Ellis and Shepherd (1975), using the same experimental design as Hillyard (1973) but with a shorter exposure duration of the test stimulus (15 ms), also recorded their subjects' accuracy in making same/different judgements on inverted faces. The study by Yin (1970) found that patients with right posterior lesions performed better with inverted faces than did patients with left sided damage, suggesting that the recognition of inverted faces is not specifically carried out in the right hemisphere. Ellis and Shepherd therefore predicted that while upright faces would be better recognised if presented in the left visual field, inverted faces would be more accurately recognised if they occurred in the right visual field. The results replicated the left field superiority for upright faces found in previous investigations and also showed this to be true for inverted faces. There was no difference between the upright and inverted conditions. Ellis and Shepherd conclude from these findings that the hypothesised face specific system may not be orientation specific or alternatively, that the right hemisphere is simply better at recognising any complex pattern.

A left visual field advantage has also been reported for coloured pictures of unknown faces (Ellis and Shepherd 1973), for faces showing either a neutral or emotional expression (Suber and McKeever 1977) and those with both positive and negative emotional expression (Ley and Bryden 1979).

These experiments on normal subjects have always employed anonymous faces and the question as to whether a hemispheric difference would be found with the recognition of well known faces (i.e. faces to which

verbal labels have been long attached) remained open until the study by Marzi et al (1974). Manual discriminative reaction times to brief tachistoscopic presentation of famous faces were found to be significantly faster when shown in the right visual field and the right field was similarly found to be superior for accuracy of recognition in a series of snapshots of famous people. In an experiment using anonymous face stimuli which had previously yielded a left visual field superiority for discriminative reaction times, subjects who had subsequently been taught to allocate a name to each stimulus produced the opposite effect, i.e. faster times with the right field. In a later study by Marzi and Berlucchi (1977) in which subjects were shown famous faces and were requested to identify each face by a proper name or an unequivocal definition, accuracy was again found to be better with those faces presented in the right visual field. This finding conforms with the results of Levy et al (1972) on commissurectomised patients, in that if linguistic processing is involved, the subject's response is dominated by the left hemisphere, favouring the right visual field.

These data can hardly refute the overwhelming evidence pointing to a specialisation of the right hemisphere for the processing of unknown faces in normal subjects, yet they do raise the interesting possibility that under certain conditions the recognition of faces may rely on cognitive strategies which require the preferential involvement of the left hemisphere.

Summary

In conclusion of this section, the information regarding hemispheric functional roles, obtained from patients with asymmetrical brain lesions, certainly suggests a strong association between the right side

and facial recognition. This evidence is strengthened and extended by the observations on facial perception in patients with surgically separated hemispheres, except when linguistic processing is also involved. The results from studies on prosopagnosia are not quite so straightforward. The exact nature of this disorder is still in dispute, for it seldom occurs as an isolated deficit though the accompanying defects are similar in the majority of cases. Reports of a dissociation between familiar and unfamiliar facial recognition in these patients add a further complication, as do the clinical analyses which have pointed to either bilateral or unilateral, right sided lesions. Postmortem studies indicate the importance of occipitotemporal damage particularly within the right hemisphere, but the presence and contribution of frequent, symmetrical left sided lesions still remain to be explained. Tachistoscopic half field experiments in normal subjects have produced a clear indication of a right hemisphere advantage in facial perception, except when linguistic interference is involved (as with the commissurectomised patients).

Taken together, these various sources of evidence point strongly to a right hemisphere superiority in facial processing. In an attempt to explain the observations that are at variance with this statement, one could suggest that the association between facial recognition and the right hemisphere is only a general rule. Accordingly, the findings which do not conform, for example the differences between known and unknown faces, the changes that occur with language involvement and the bilateral lesions found with prosopagnosic postmortems, might merely indicate that under special circumstances the question is not one of absolute dominance but rather one of relative hemispheric specialisation or different localisation within each hemisphere (Warrington and James, 1967).

Given these experimental indications of a cerebral asymmetry for

faces the possibility that such specialisation might be mirrored in electrophysiological studies seemed worthy of investigation. Such a technique offers a clear advantage over traditional methods because it allows assessment of function within each hemisphere simultaneously as well as providing indications of functional localisation. Differences in the brain's response to familiar and unfamiliar faces should promote a clearer understanding of the mechanisms that underlie recognition and comparison of the waveform recorded in response to faces and other complex stimuli might help to explain the special nature of face processing. Before describing the experiments that were performed the methodology behind this physiological approach will be explained.

CHAPTER 2

INTRODUCTION PART 2

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The Averaging Technique.

One physiological technique which has proved useful in investigating the function of brain areas is the averaged evoked potential (A.E.P.). Electrical impulses are recorded from electrodes attached to the scalp, and the resulting waveform is termed the electroencephalographic trace, (E.E.G.). Stimuli are presented and each one triggers a computer to store a sample of E.E.G. at a specified time. This pre-programmed computer with an averaging facility adds up consecutive samples of brain activity. As the samples of E.E.G. are time-locked to the stimuli any response which occurs consistently will gradually summate, whereas the on-going E.E.G. activity, bearing no constant time relationship to the stimulus, will gradually cancel out. The averaged response to a series of stimuli is then displayed in graphical form. The inference that such a response does however signify functional brain activity, which is related to a certain stimulus modality, relies on a number of assumptions. Firstly, that cortical neurones are stimulus specific and their behaviour (activation or quiescence) is reflected in the evoked potential waveform. Secondly, that a response occurs localised to its assumed functional area and that such intracranial activity is accurately recorded by scalp electrodes. These assumptions will be considered in turn.

Neuronal Specificity.

Interpretations from studies investigating the relationship between intracortical neuronal mechanisms and the components of the visual evoked potential are complicated by differing results. For

example, Fromm and Bond (1967) using light flashes and simultaneously recording single neurone activity and the evoked potential over the exposed surface of the posterior lateral gyrus in the cat, describe cells activated specifically by photic stimulation. They also found the relation between the surface V.E.P and intracellular activity such that neurones tended to fire during surface positive waves, and to cease firing during surface negative waves. A similar correlation between inhibition and surface negativity has been described by Humphrey (1968), recording potentials in response to electrical stimulation over the motor cortex in the adult cat. In contrast however, Creutzfeldt et al (1969), again using light flashes and recording from area 17 in the cat, observed polarisation (inhibition) of cortical cells coinciding with surface positivity in response to the light stimuli. Interpretations are further complicated by the lack of uniformity of different cell groups within the cortex so that complex interactions of depolarization and polarization may occur (Creutzfeldt and Kuhnt, 1967).

The Relationship between Neuronal Activity and the E.P. Waveform.

Whilst these studies do indicate that cortical neurones are selective in their response to stimuli, conflicting findings arise concerning how cell activation and inhibition are related to the E.P. waveform. Humphrey (1968) gives a detailed explanation of these apparent contradictions and states "one cannot assume that cells of the same shape, subjected to synaptic inputs of the same kind and at similar somadendritic locations, will in general generate cortical surface potentials of a given polarity". He concludes that many factors must be considered before attempting to explain the inconstant phase relationships, for example: the somadendritic location and spatial extent

of conductance changes, the dendritic lengths of the cellular population involved and the distribution of responding cells over cortical depth. The situation is therefore considerably complex and while further single cell and E.P. correlations may be helpful in elucidating the neuronal substrates of the V.E.P. in experimental animals, more direct data are required to explain the surface potentials recorded in man. Meanwhile, the origins of human evoked potentials remain obscure.

Localisation of E.P.s to Functional Areas.

Studies on the localisation of the E.P. waveform to assumed functional regions are less contradictory. In man, the topographical distribution of visual evoked responses recorded with electrodes over the surface of the occipital cortex has been investigated by Hirsh et al (1961). In a series of eleven patients, undergoing neurosurgical procedures with local anaesthesia, electrodes were placed on the exposed medial and lateral surfaces of the occipital lobe. Stimulating with flash at a rate of 1/sec and using superimposition techniques, they were able to record responses from both medial and lateral surfaces, maximum amplitude being opposite the calcarine fissure. Early components occurring at 40-50 msec were present over both surfaces, but a later component at 90-100 msec was only recordable over the lateral region. They noted that the scalp evoked potential (as described in the literature and not simultaneously recorded) resembled the response obtained over the lateral surface of the occipital lobe but not that from the medial surface. Electrographic responses from implanted electrodes in response to flash and patterned light (geometric shapes and pictures) have been reported by Perez-Borja et al (1962). Recordings were made from the occipital lobes of 26 patients using a total of 167 depth electrodes.

Responses to single flashes of light were localised to discrete areas of the occipital lobe in or near the calcarine region, whereas the responses to patterned stimulation (lamda waves) were located not only in the medial portion but also in the inferolateral and occasionally in the superolateral portion of the occipital lobe.

Electrical mapping of somatosensory areas in man shows similar localisation. Kelly et al. (1965), in the waking patient, initially identified the motor and somatosensory hand areas by electrically stimulating the cortical surface. Subsequent stimulation of the median nerve evoked large amplitude responses limited to these areas and the immediately neighbouring cortex. These workers report that their transcortical waveform was comparable to the response elicited by median nerve stimulation and recorded from the scalp in normal human subjects, described in a separate study by Goff et al. (1962). In order to determine the location of the human primary auditory area, a systematic exploration of the superior temporal plane has been undertaken by Celesia and Puletti (1969). Average responses to binaural clicks at 1/sec were recorded with the use of a multicontact depth probe from the exposed cortex in five patients under local anaesthesia. The responses were obtained from a small area on the superior surface of the temporal lobe, representing the primary auditory area in man and corresponding to the cytoarchitectonic fields of Brodman. However, comparing their intracranial results with the waveform recorded over the scalp described by other authors, Celesia and Puletti report that the latency, duration and configuration of the scalp potentials were not comparable to those recorded from the primary auditory cortex.

Correlation between Scalp Recording and Cortical Activity.

Simultaneous recordings from intracranial and overlying scalp electrodes are clearly of greater importance in determining how faithfully the activity at the scalp reflects the activity of the cortex. Direct comparisons have been made in the awake Rhesus monkey, with 1/sec flash stimuli, by Vaughan and Gross (1969). Recording simultaneously from cortical, epidural and subdermal electrodes placed above each other over striate and parietal cortex, they found the waveforms of the responses recorded over the same sites to be essentially similar. Opportunities for human intracranial studies are rare and there are few reports of such simultaneous V.E.P. recordings. In man, Rayport et al (1964) concluded that the averaged scalp potential reflected quite accurately the responses evoked in the posterior margin of the mesial occipital cortex. Recording from unanaethetized human subjects, they describe a complex V.E.P. characterized by a sequence of positive-negative deflections with several fast waves. Scalp electrodes showed attenuation of fast components but preservation of latency and form of the slower components of the early response. Corletto et al (1967) have reported V.E.P. findings in an epileptic patient who had to undergo surgical ablation of the left occipital pole. Comparisons were made (a) between the averaged visual evoked response recorded from the scalp and that recorded directly from the visual cortex and (b) between scalp responses recorded before and after surgery. The averaged evoked response, bipolarly recorded from the exposed cortex between an electrode placed on the occipital lobe (area 17) and another in front of the visual region, was remarkably similar to that recorded by scalp electrodes having an analogous spatial arrangement. The ablation of the occipital pole greatly reduced the amplitude of waves with peak latencies between 50 and 110

msec but did not affect the late components with latencies over 120 msec. These findings suggest that the main site of production for waves occurring between 50 and 110 msec is in area 17 (the ablated neuronal population), and that the later components are probably generated elsewhere.

However, Cooper et al (1965) state "the scalp E.E.G. is a very poor indicator of the complex local activity going on at cortical level." In their study, intracranial recordings were made from chronically implanted electrodes inserted in twelve patients. Activity evoked by single flashes of light was recorded from an occipital scalp electrode (O2, right occipital) and compared with activity occurring simultaneously in a depth electrode (lying very close to the dura immediately beneath the O2 surface electrode). The cortical response, consisting of a large positive deflection, was not seen in the scalp recording; only synchronous activity from a relatively large area of cortex could be observed. Unfortunately, these results are of doubtful significance because the authors photographically superimposed only 10 sweeps of occipital scalp activity, a technique which frequently fails to define signals of low amplitude. Heath and Galbraith (1966) have also demonstrated differences in the evoked potentials recorded simultaneously from the scalp and subjacent cortex in man. Cortical electrodes, located on the arachnoid mater overlying the striate area and rostral temporal cortex were implanted in two patients for therapeutic reasons. Scalp electrodes were placed at analogous sites (determined radiographically). An early positive component, evoked by flash at 1/sec, occurred in both occipital scalp and depth recordings but there were marked differences between the occipital scalp and the occipital cortex for components

between 100 and 300 msec. The striate area showed a well defined tri-phasic response while only a long duration positive wave appeared at the scalp. Yet recordings from the temporal cortex and the scalp were similar throughout the first 400 msec. The authors suggest that the later components recorded from the occipital scalp may therefore originate primarily in the temporal cortex, a theory not unlike that put forward by Corletto et al (1967) formulated from the V.E.P. findings before and after occipital ablation, described earlier.

Studies of simultaneous human surface and cortical recordings, using visual stimuli other than flashes, are rare. Brindley et al. (1978) is the only report to date of simultaneously obtained scalp and depth recordings to pattern reversal in man. Responses from electrodes implanted in the lateral lobes of the cerebellum were of similar form and latency to those recorded with right and left occipital scalp electrodes. (It was concluded that cerebellar V.E.P.s occur by volume conduction of the cerebral response through the tentorium). A search for the neural generator or generators of the scalp P300, in response to more complex visual stimuli, has been carried out by McCarthy and Wood (1985), in patients taking part in an epilepsy surgery programme. Recordings were made from four implanted, multicontact depth probes (posterior temporal, mid-temporal, frontal and motor cortex) allowing sixty-four simultaneous E.P. channels. Electrode positions were estimated from X-rays taken during stereotaxic surgery. The patients undertook a target detection task in which the letters XXXX and OOOO were viewed but only the latter attended to. Two distinct E.P. patterns were identified, one in the medial temporal lobe and the other at locations throughout the frontal lobe. The medial temporal waveform covaried with P300 although it did not faithfully reproduce the waveform at the scalp. Because the patterns

overlapped in time with each other McCarthy and Wood conclude that scalp P300 is likely to be a composite of multiple generators.

Although these studies have produced some conflicting results there is a measure of agreement and a topographic relationship between scalp recorded activity and cortical anatomy has been demonstrated. The consensus appears to be that early components of the visual evoked response certainly reflect activity from the sensory specific cortex (i.e. occipital) and that these waves show a similar waveform with both depth and scalp electrodes. In contrast, the later components, with latencies greater than 120-150 msec are not analogous at occipital scalp and cortex and may therefore be generated outside this region. It must be remembered that the above findings are based largely on the results obtained from patients with neurological or psychiatric disorders in whom neural organisation may have been impaired. It is important therefore to review V.E.P. studies which use a convenient, non-invasive method in normal, intact subjects. Whilst the evoked potential technique can be used in conjunction with stimulation of visual, auditory or somatosensory modalities as already described, only those studies exclusively concerned with the recording and analysis of the visual evoked response will now be discussed in more detail.

The Normal Surface V.E.P.

The surface V.E.P. from normal subjects has been studied extensively. The waveform, which is displayed as a plot of voltage against time, usually lasting 200 to 1000 msec, consists of various up-going and down-going peaks which are labelled according to their apparent polarity and latency. (To induce parity of nomenclature, there is a convention in electroencephalography which recommends that when a black

lead, i.e. Grid 1 of the input amplifier, becomes electro-negative with respect to the white or Grid 2, the recording pen makes an upward deflection. This is explained in more detail in the Method section). Between different subjects and different laboratories considerable variations can occur (Jonkman, 1967; Aunon and Cantor, 1977). Before reviewing the reported studies a number of points concerning these differences should be made clear.

Factors Causing Variations in the E.P. (i) Reference Electrode

Some of the variation in the reported literature can be attributed to methodological problems, the fact that the morphology and topography of the V.E.P. are altered by various factors including the electrode reference position, the eliciting stimuli and the cognitive state of the subject. For example, when looking for small differences in amplitude or latency between responses from right and left hemispheres, it is common to select a unipolar electrode montage. Each channel records between one "active" electrode on the scalp and one relatively "indifferent" electrode elsewhere. In theory, each channel then records solely the voltage fluctuations from a single electrode on the scalp and any asymmetries are unambiguous. However, there are major practical difficulties with selection of a truly neutral reference, for the ear, nose, chin and neck invariably conduct electrical activity from the nearest part of the brain and may be contaminated by a variety of non-cerebral potentials (muscle activity and electro-oculographic potentials, particularly blinks) which will then be recorded on all channels. Placing the reference away from the head and neck immediately introduces the electro-cardiogram, the amplitude of which may be several times that of

the E.E.G. Particularly important in experiments investigating hemisphere asymmetries is the choice of a symmetrical reference site. A unilateral ear lobe, for example, may itself be affected by just those experimental manipulations intended to induce laterality effects. The most appropriate site for V.E.P. studies of laterality would appear to be an "active" midline (i.e. symmetrical) reference to which all other scalp electrodes are referred, providing the distribution of the evoked potential under investigation and the possibility of any electro-oculographic artefact are taken into consideration.

(ii) Stimulus Factors.

Factors relating to the eliciting stimuli can also influence the resulting V.E.P. Each of the two general types of visual stimuli most often used, unpatterned flashing light and patterned stimuli, produce differing results (Spehlmann, 1965). Two major variables, intensity (Tepas et al, 1974) and rate of flicker (Regan, 1972) affect the unpatterned flash V.E.P. As intensity decreases the peak latencies of the individual components become longer and the amplitude is attenuated. Increasing the rate of flash produces steady state V.E.P.s, the peaks occurring as a function of the flicker rate (Ciganek, 1961).

(iii) The Cognitive State of the Subject.

The attentional state of the subject can also significantly alter the amplitude of the late V.E.P. components. Courchesne et al (1975) found infrequent target slides (which were task-relevant) evoked a much larger late positivity than did frequent, but irrelevant stimuli. Galin and Ellis (1975) and Papanicolaou (1980) similarly claim that the amplitude and symmetry of the earlier components are affected by attention and task relevance. It is important therefore to bear in mind

these factors when comparing studies and assessing the reasons for reported asymmetries.

V.E.P. Studies involving Simple Stimuli.

Human V.E.P. studies can, in general, be divided into two kinds; those that employ simple stimuli and those in which the stimulation is more complex. The first type (involving, for example, flash and pattern reversal) usually investigates the early components (less than 150 msec) which are related to factors concerning the physical properties of the stimulus. The later part of the waveform (200 - 400 msec) is relatively modality non-specific but strongly influenced by the cognitive processes of the subject and is therefore usually investigated with more elaborate stimuli. Studies employing simple stimuli will be reviewed first followed by those involving complex stimulation, which are more pertinent to the present study.

The Flash Evoked Potential.

Cobb and Dawson (1960) were the first to apply an averaging technique to the examination of visually evoked potentials. In response to flash stimuli (1 every 2 secs) they reported a waveform consisting basically of four components, a small positive and a small negative wave with peak latencies of 20-25 and 40-50 msec, followed by larger positive and negative waves with latencies of 55-65 and 90-100 msec respectively. After this sequence, "a series of waves with a period of about 100 msec occurred ... but the recording methods available were not convenient for studying this later part of the response". They noted that amplitudes diminished and latencies increased with decreasing brightness of the flash. Subsequent investigators have, in general, confirmed these observations though variations in detail occur. Ciganek (1969), in a

study of twenty subjects stimulated with their eyes closed at a random flash rate ranging from one every 3 to 6 seconds, describes seven components occurring within the 0-300 msec analysis time. The group mean latency of the wave with maximum amplitude (wave IV), recorded bipolarly between Oz and Pz, was 110 msec (SD 10.98). Peak latencies for components later than 160 msec were not provided. Richey et al. (1971), describing the results from fifty subjects serving as normative data in a clinical trial, report five waves within their 0-250 msec averaging period. Subjects were stimulated with both eyes open, at a random flash rate of one every 4 to 6 seconds and electrode positions included frontal, central, temporal and occipital areas, all referred to joined ears. The main positive component had a group mean latency of 118 msec. Latencies of components occurring after 150 msec were again not given. The results of Harding (1982) are very similar but include latencies from differing age groups. The mean latency of the major positive deflection, recorded from Oz to Pz, for subjects aged 18 to 30 years was 110.6 msec (SD 11.9) and for those between 65 and 75 years, 117.2 msec (SD 10.7). Also described is a subsequent positivity, "P3", included within the 250 msec averaging period with a mean latency of 200.8 msec (SD 23.7) and 213.9 msec (SD 26.2) for the young and old age groups respectively.

The symmetry of these components has been evaluated by Kooi et al. (1965) in a group composed of 80 normal adults acting as controls for a study investigating the V.E.P. in patients with field defects. Flashes were given randomly, one every 4 to 6 seconds, and presented with the eyes open. Electrode derivations included right and left frontal, occipital, parietal, posterior-temporal and central areas referred to joined ears. The analysis time lasted from 0-250 msec. Five consistent

waves were recorded, including a large positive deflection occurring with a mean latency of 118 msec, maximum occipitally. Amplitude asymmetries occurred for all components but were variable, with waves being smaller on either the right or left side. No overall significant hemisphere preference was found. However, Lewis et al. (1970) have reported the flash evoked response to be larger over the right central area than the left in 3 out of 9 normal controls. There were no significant asymmetries in occipital regions. The difference could be attributed to a large negative wave peaking at approximately 125 msec which appeared with a mean amplitude of 17.5 uV on the right and 11.9 uV on the left. The small number of subjects precluded statistical analysis.

In a study of the variability of the flash response as a function of scalp area, time and subject, Werre and Smith (1964) found considerable differences between subjects. Less salient were those between areas of the head and in an individual studied repeatedly. Similarly, Bourne et al. (1971) reported that the repeatability of the flash V.E.P. (from the same location and under the same stimulus conditions) was excellent.

In summary, these studies show that the V.E.P. to binocular flash is variable, more so between than within subjects. The component of maximum amplitude (within the first 150 msec of the waveform) occurs between 110 and 118 msec, slightly increasing in latency with age. (This component has been termed P100 in more recent nomenclature due to its polarity and latency and will subsequently be referred to as such). It is recordable from occipital electrodes and there have been no reports of a marked asymmetry in this region. A later positive wave has also been described with a peak latency of approximately 200 msec. Whilst most of the above studies have recorded over the occipital region (often only

from this area), more topographical investigation of flash V.E.P. with simultaneous recording from various scalp regions should be performed, in order to relate the components with particular areas of cerebral cortex, since surprisingly few data are available.

The V.E.P. to Flashed Pattern Stimuli.

Simple stimuli may also include a flashing pattern which is usually produced by illuminating a transparency of black and white checks using a photostimulator. With patterned stimuli the response may be altered by the size of the check or stripe (Parker and Salzen, 1977) and by the location of stimuli on the retina (Andreassi et al., 1975). Maximum amplitude is found with stimulation of the central three degrees of the retina; outside this area it is greatly reduced (Harter, 1970). In a comparison of the responses to unpatterned white light flashes and patterned flash (translucent checkerboard pattern), Allison et al. (1977) pointed out that analysis of components in the latency range of 80-140 msec was difficult due to within and between subject variability. However, they report the components and topography to be similar for both types of flash. Stimulating the right eye only, at a rate of 1 flash every 4 seconds, they describe nine alternating negative/positive waves between 85 and 300 msec, but because they have adopted the unusual convention of displaying positivity as upwards at the active electrode, it is difficult to decide which wave, P95 or P130 corresponds to conventional "P100". In contrast, Spehlmann (1965) found dissimilarities between these two types of stimulation. Recording from the inion referred to the ipsilateral ear, the main positive component to unpatterned flash occurred with a latency of 80-120 msec, whereas the maximum surface positivity with patterned flash appeared around 180-250 msec. The

waveform distributions though were similar, with both sets of responses reaching their maximum 3 cms anterior and lateral to the inion, becoming inconspicuous at distances of 5 cms.

The Pattern Reversal V.E.P.

It has been pointed out by Regan (1972) and Spekreijse et al. (1973) that a flashed patterned stimulus contains two parameters which change simultaneously so that there is an abrupt increase in brightness as well as the presentation of the pattern. There is also an interaction between brightness and pattern change which produces a pattern V.E.P. contaminated by luminance changes. To avoid this complication a pattern with a constant average luminance can be presented by pattern reversal. Checks are visible all the time but in order to maintain a constant luminance level one half of the checks increase in luminance whilst the other half decreases. This is usually accomplished by a rotating mirror which causes the checks to move through a distance equal to one check size (Halliday, McDonald and Mushin, 1972).

Since the first demonstration of the efficacy of this method, it has been applied to many different clinical problems. The following descriptions of the pattern reversal V.E.P. are taken from control data provided by such clinical studies. Each one describes the results to monocular stimulation at a reversal rate of once every 600-800 msec. Halliday and Michael (1970), producing pattern reversal with an alternating shutter technique, report a prominent positive wave with a mean peak latency of 100 msec. In a subsequent study using a rotating mirror, Halliday, McDonald and Mushin (1972) recorded an identical positive peak with a group mean latency and amplitude of 120.1 msec (SD 4.0) and 7.74 uV (SD 3.3) respectively. The increased latency observed in

the latter investigation was due to the small but constant delay introduced by the slightly slower stimulus associated with pattern movement compared with the alternating shutter technique. (With an improved mirror system, Halliday, McDonald and Mushin (1973), give the mean latency of the first positive component as 103.8 msec). Later components were not described in detail but it is evident from their figure, illustrating a typical response in a healthy subject, that a subsequent single positive component occurs between 200 and 300 msec. Asselman et al. (1975), in a series of 37 healthy controls, give the mean latency and amplitude of their first positive deflection for subjects aged less than 60 years as 90.5 msec (SD 4.3) and 9.2 uV (SD 4.8). Over the age of 60 years the mean latency was significantly longer at 97.2 msec. They noted that their main peak occurred considerably earlier than that described by Halliday, McDonald and Mushin (1973), due to the speed of the mirror movement. Preliminary experiments, undertaken to find the optimum electrode placement, indicated the maximum response to occur 5 to 10 cms above the inion. According to Shahrokhi et al. (1978), from evidence based on six autopsy observations, this location of the occipital electrode corresponds roughly to the mid-portion of the calcarine fissure. Hennerici et al. (1977), recording from an electrode 6 cms above the inion referred to linked ears, report a mean latency of 102.5 msec (SD 2.9) for their first positivity. This latency was unaffected by age up to 65 years. Whilst the post-stimulus analysis time lasted 450 msec, the latency and amplitude of the subsequent waveform was not considered. Zeese (1977) and Shahrokhi et al. (1978) provide similar results, their mean latencies for P100 being 103 msec and 102.3 msec respectively. Again, no mention was made of later components in either

paper, but from the illustrations it is evident that a single positive peak between 200 and 300 msec follows P100.

Top: from Zeese et al. (1977) Bottom: from Shahrokhi et al. (1978)

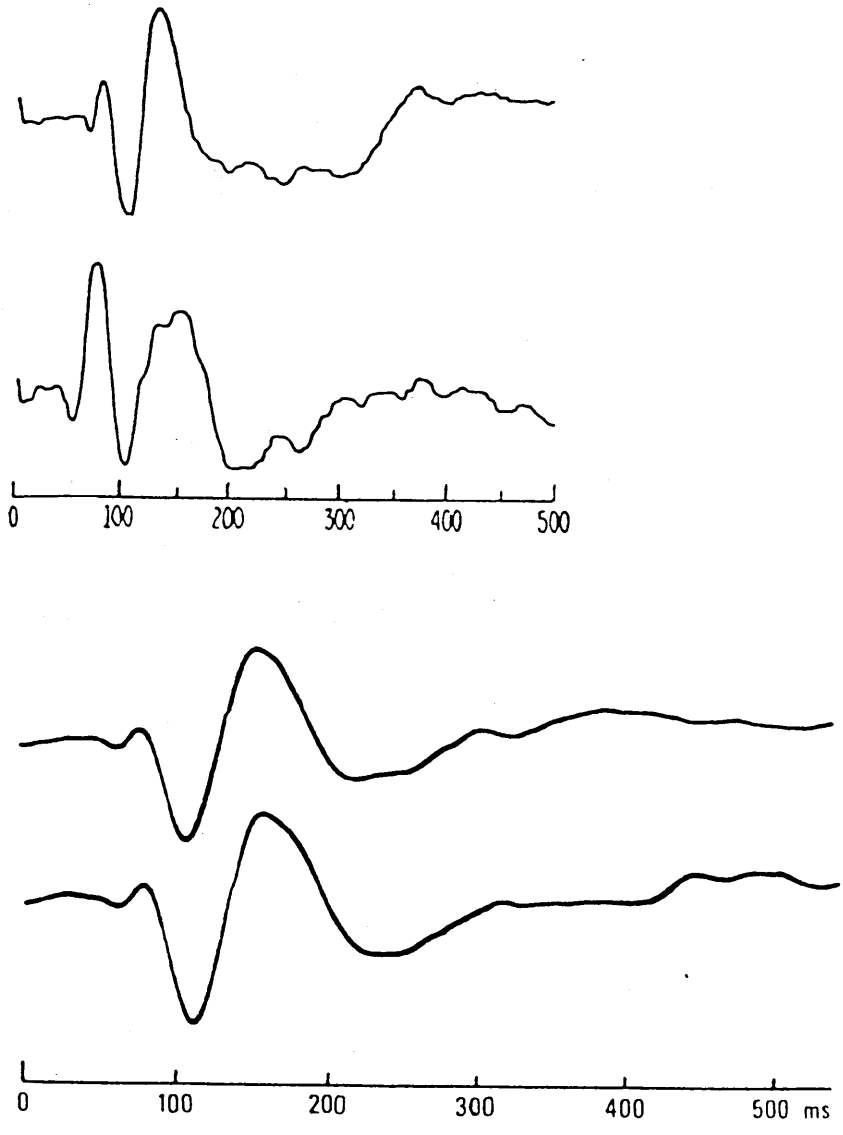


Fig 2:1

In the Department of Clinical Neurology at the Radcliffe Infirmary during 1982, a group of 20 normal volunteers, participating as controls for clinical research, received monocular pattern reversal stimulation at 2/sec. This experiment involved exactly the same equipment as that used in the present thesis. The group mean P100 latency and amplitude were 98.9 msec (SD 5.14) and 12.0 uV (SD 5.6) respectively.

The location of the source of P100 to pattern reversal has been explored by Jeffreys and Axford (1972) and Halliday and Michael (1970). Jeffreys and Axford, using a dipole model based on the known retinotopic organisation of the striate cortex to explain component distributions, suggest that P100 is produced in extrastriate cortex. Evidence comes from polarity reversal of this component across the midline with upper and lower, but not with right and left half-field stimulation. Halliday and Michael (1970) reached the same conclusion for the origin of P100, though their reasons for doing so are not strictly comparable to that of Jeffreys and Axford.

Patients with specific lesions of the visual cortex provide further insight into the possible generator sources of P100. Bodis-Wollner et al. (1977) found steady state pattern evoked potentials present in a patient who had bilateral destruction in cortical association areas 18 and 19 but preservation in primary area 17. Conversely, Celesia et al. (1980) found essentially normal transient pattern E.P.s in a patient with bilateral preservation of areas 18 and 19 but destruction of area 17. More recently, Celesia (1985), using combined CT scan and PET neuro-imaging techniques in a patient with cortical blindness, has concluded that small regions of both areas 17 and 18 are required for the preservation of the early pattern evoked response.

In a comparison of the V.E.P. to flash and pattern reversal, Allison et al. (1977) report the response with pattern reversal to be simpler in waveform, consisting in the occipital region of a negative/positive/negative/positive sequence with latencies of 80, 100, 130 and 200 msec respectively. They regarded the relationship of these components and those recorded to flash as uncertain and therefore did not generalise the flash V.E.P. topography to that of pattern reversal.

Hughes et al. (1982), comparing the same two types of stimulation, describe similar waveforms; the latencies of the two major positive peaks occurring at approximately 100 and 200 msec. To pattern reversal, peaks showed significantly smaller standard deviations and lower amplitudes, with an earlier latency of P100.

In general, these studies show that the presentation of pattern reversal evokes a V.E.P. which differs slightly from that obtained with homologous light stimulation. The first main positive peak, P100, occurs with an earlier latency of 90 to 104 msec, with less scatter which is reflected by the smaller standard deviations. It is recordable, like the response to flash, with maximum amplitude over the occipital region, 5 to 10 cms above the inion; the extrastriate cortex having been proposed for its site of origin. Whilst the later part of the pattern reversal V.E.P. waveform has rarely been described, a subsequent positive component between 200 and 300 msec appears in the illustrations of some studies.

In conclusion of this section, it is evident that simple stimuli, such as flash and pattern reversal, presented to subjects in whom no task is required, evoke a large P100 wave and a subsequent positivity which occurs between 200 and 300 msec.

V.E.P. Studies Involving Complex Stimuli.

Although this late positive potential of the human evoked potential, the P3 or P300 wave, has been extensively investigated in the auditory modality, it has been less often examined in response to visual stimuli. Numerous researchers have suggested that the late P300 auditory component reflects cognitive events. It is large, for example, in response to target detected tones and small or non-existent if subjects

are not attending. But P300 can also be evoked by a stimulus that occurs infrequently yet requires no response (Ritter et al, 1968). Obtained under these conditions, this component has been variously correlated with cognitive acts such as orientation, task-relevant surprise, information acquisition and uncertainty reduction. Sutton et al. (1965) incorporated both visual and auditory stimulation in a study designed to test the effects of uncertainty on the late E.P. components. Recording from a single channel (near the vertex referred to joined earlobes), they detected a large positive deflection at 300 msec, the amplitude of which was larger for uncertain than for predictable light flashes. Using more complex stimuli, Courchesne et al. (1975) have examined the late V.E.P. components during a visual discrimination task. Eighteen adult subjects were presented with slides of rare, task-relevant numerical stimuli (the number 4) amongst non-attend figure 2's, and their responses to these were compared with those to rare, task-irrelevant stimuli. The irrelevant slides were of two classes: i) easily recognisable (simple, geometric shapes) and ii) completely novel (complex, abstract drawings). Recordings were made from midline electrodes, Fz, Cz and Pz referred to the right mastoid. Unfortunately, the waveform terminology used is unconventional with positivity indicated as an upward deflection, but it seems fairly certain that their "N2" wave (230 to 320 msec) is synonymous with the usual P300. N2 was smaller to the common slides (figure 2's) than the infrequent number 4's. Novel slides (complex drawings) evoked a larger N2 wave than either simple stimuli or rare task-relevant number 4's. Apparently, as with the auditory E.P., P300 waves can be elicited by both task-relevant visual stimuli and by slides that are seemingly irrelevant to any ongoing task.

Few visual evoked potential studies on adults have been reported where the only task involved is to watch the stimulus, and there appears to be no description of a study specifically designed to investigate the evoked response to faces. In a study by Cohen and Walter (1966), subjects viewed meaningful slides (geometric shapes and nude figures). The experiment was designed, however, to study the contingent negative variation prior to a visual stimulus. The paper does though include an illustration of a subject's responses to complex pictures, without a conditional stimulus. With the single channel montage (vertex-mastoid) an early wave at approximately 100 msec is present followed by a larger positivity between 250 and 400 msec. In an attempt to differentiate positive, negative and neutral cognitive associations, Lifshitz (1966) presented male subjects with complex stimuli, slides categorised as female nudes, repulsive medical and indifferent scenic. An occipito-parietal bipolar lead showed a fairly consistent wave between 250 and 400 msec, with a mean latency of 320 msec, which showed an amplitude increase when slides were focussed as opposed to defocussed. Lifshitz suggested that the enhancement was related to cognitive aspects, rather than to the physical properties of the stimuli.

At this point it should be noted that an increase in amplitude of the evoked potential does not necessarily reflect an increase in brain function but it is a reasonable assumption based on the amplitude maximum found with direct cortical recordings which correlate with the known, human cerebral anatomy in the three modalities, i.e. visual (Hirsch et al, 1961), somatosensory (Kelly et al, 1965) and auditory (Celesia and Puletti, 1969).

In a search for an E.P. paradigm that could be used to investigate attentional processes in infants, Shulman-Galambos and Galambos (1978)

recorded the V.E.P. in response to complex visual stimuli consisting of coloured photographic slides of scenes, both focussed and defocussed. Recordings were made from sixteen right handed adults aged 18 to 25 years, with electrodes placed over the right and left central regions (C4 and C3), referred to linked earlobes. No task was given to the subjects, they were merely required to watch the slides. The evoked response consisted of a complex series of late waves including a positive component in the P300 range with a mean latency of 366 msec, (SD 25), which was large when the slides were focussed and smaller when they were not. The P300 amplitude did not decline with stimulus repetition whereas the amplitude of an earlier component (P2) did. Whilst no consistent hemisphere asymmetry was produced the authors state that "the response amplitude at one hemisphere did indeed differ sometimes from that at the other, the right usually being the larger, but the small size of the sample precludes a meaningful statistical statement of difference." They concluded from this experiment that the mere presentation of complex stimuli, with no requirement that subjects should overtly respond, can evidently evoke a complex series of cortical potentials which are labile and therefore seem to be controlled more by endogenous than by exogenous (stimulus related) factors. Because P300 showed no amplitude decline with repetition and was largest when the stimulus was recognisable (i.e. in focus) the authors suggested that this wave may reflect some sensory or cognitive process which differs from that controlling P2. It should be pointed out that there is an alternative way of interpreting the different results obtained from focused and defocused stimuli. Slides which are in focus are clearly more "meaningful" than defocused slides and amplitude changes may well be interpreted as associated with

cognitive processing. But, on the other hand, when a slide is in focus the contrast borders are sharper and, as with pattern reversal, it is these contrast changes upon which the evoked potential is dependent. It could easily well be argued that the amplitude changes found with focused slides are related not to cognitive events, but to the physical properties of the stimuli.

In the above study, the cognitive events associated with the generation of P300 remained uncertain because the subjects were not asked to reveal their reactions to the stimulus they had experienced. Neville et al (1982) have extended this work in order to investigate whether systematic E.P. changes occur as a function of a subject's perception and evaluation of a stimulus. Nine normal adults viewed coloured slides of people, places and paintings at irregular intervals, randomly interspersed with blank flashes of light. Evoked potentials were recorded from the midline in frontal, central and parietal areas (Fz, Cz and Pz) and from right and left parietal sites (P4 and P3), all referred to the right mastoid. Immediately after presentation of the slides subjects were asked to state which ones they had recognised and the degree of surprise they had experienced at the time. Responses were then segregated and averaged according to recognition and surprise. The results showed that P3 (350 to 500 msec) changed systematically as a function of the subject's surprise ratings, occurring with larger amplitudes to highly surprising slides than to those rated medium and low. This component was also clearly larger for slides that were recognised ($p < 0.01$). The effect of recognition was asymmetrical at the parietal sites with the P3 wave tending to be significantly larger for recognised than for unrecognised slides at the right hemisphere electrode. This experiment indicates that the process of recognition could be a major determinant of P300

amplitude. Further investigation of this potential might therefore serve to measure the integrity of the perceptual and memory systems that underlie this complex cognitive activity.

Accordingly, the present study at first attempted to ascertain whether in fact a response could be evoked by slides of faces. From the evidence provided by studies using simple visual stimuli it was expected that P100 would occur in response to the physical factors of the slide presentation, (i.e. the flash). Because faces are complex, it was predicted that P300 would be present, indicative of a relationship between this component and the perception and evaluation of the meaningful properties of the stimuli. It seemed probable, from evidence based on lesion studies, that if present, P300 might be topographically maximal in posterior temporal and occipital regions.

CHAPTER 3

GENERAL METHOD

1. SUBJECTS

A. Right handed controls Experiment 1
B. Left handed controls Experiment 2
C. Right handed controls Experiments 3 and 4
D. Patients

2. RECORDING

A. Preparation of subject
B. Electrodes and Electrode Placement

3. STIMULI

Slides of:-

Known faces
Unknown faces
Geometric designs
Inverted known and inverted unknown faces
Words

Pattern reversal

4. INSTRUMENTATION AND RECORDING SYSTEM

Averaging

Processing

5. STATISTICS

1. SUBJECTS:

Normal controls were unpaid volunteers who had no past history of neurological disorder and were not suffering from any known disease. All right handed controls were friends or work colleagues of the experimenter. Left handed subjects proved scarce and therefore more difficult to obtain; ten were friends or work acquaintances and the remaining twelve were contacted through advertisements placed within the Radcliffe Infirmary.

A) Right handed subjects for Experiment 1.

Thirty right handed controls, 15 males and 15 females were examined. Their ages ranged from 14 to 60 years with a mean of 30.5 years. Twenty (12 males and 8 females) were right eye dominant and ten (3 males and 7 females) were left eye dominant. Eye dominance was ascertained by asking controls which eye they used when using only one, (for example, looking through a keyhole).

Prior to recording, a subject's visual acuity (VA) was noted for each eye separately. This was measured by reading an illuminated test chart (Rayners Simple Test Type, 89) at a distance of 6 metres, 6/9 being the accepted norm. Spectacle wearers were asked to bring their glasses with them; acuity was tested both with and without spectacles and optimal vision was then used during an experiment. Acuity, either corrected or uncorrected, was 6/9 or better in all right handed controls.

B) Left handed controls for Experiment 2.

The initial criterion for left handers was that they wrote with the left hand and to avoid the possibility of the results being contaminated

volunteers who had not changed their hand preference were included in the study. At the time of testing a modification of the Edinburgh Laterality Inventory (Oldfield 1971) was administered to assess hand preference in more detail, see Appendix A.

Twenty-two left handed controls, 15 females and 7 males were examined. Their ages ranged from 14 to 62 years, with a mean of 32.9 years. Five (1 male and 4 females) were right eye dominant and fourteen (5 males and 9 females) were left eye dominant. In 3 dominance was not obtained due to error. Visual acuity was better than 6/9 in all subjects except one whose left acuity was 6/18 corrected.

C) Right handed controls for Experiment 3.

Twenty normal right handed subjects, 9 males and 11 females, who had all previously participated in Experiment 1 were re-examined. Their ages ranged from 20 to 53 years, with a mean of 33.4 years.

D) Right handed controls for Experiment 4.

Fifteen right handed subjects, 6 males and 9 females took part. Their ages ranged from 20 to 53 years, with a mean of 35 years.

E) Patients

For Experiment 5, a 53 year old man with prosopagnosia was examined. His visual acuity was R 6/6 and L 6/9.

Experiment 6 was carried out on twenty four men who had received missile injuries to the brain during the Second World War. Their ages ranged from 58 to 71 years, mean age 64 years. One subject was left handed, the others right handed. Visual acuity was 6/12 or better in all except three.

2. RECORDING:

A. Preparation and position of Subject.

A brief explanation of the entire procedure was given initially to each subject to put them at ease. It was essential for the subjects to be relaxed because muscular tension, often a physical manifestation of anxiety, influences the character of the E.E.G. Action potentials, which occur during muscular contraction, are high frequency electrical impulses easily recorded by surface electrodes overlying paraspinal and scalp areas. They are large amplitude signals which tend to obscure the E.E.G. trace and contaminate the averaged evoked potential, (Fig 3:1). Therefore, following connection to the apparatus, in order to obtain useful results free of myogenic activity, the subject sat in a comfortable, semi-reclining chair in a quiet, dimly lit room and the recording did not begin until a satisfactory level of relaxation had been achieved. If muscle tension developed during an experiment due to the subject being in a static position, he or she was allowed to move slightly during a break in the recording.

B. Electrodes and Electrode Placement.

The head was measured and seven electrode positions were marked with a chinagraph pencil according to the 10-20 system (Jasper, 1958). T6, P4 and O2 electrodes were situated over the right side of the head in posterior temporal, parietal and occipital regions respectively, and T5, P3 and O1 were placed in equivalent positions on the left side. These six electrodes were referred to a mid-frontal reference electrode, Fz; see Fig 3:2. Careful attention was paid to cleaning the scalp area beneath

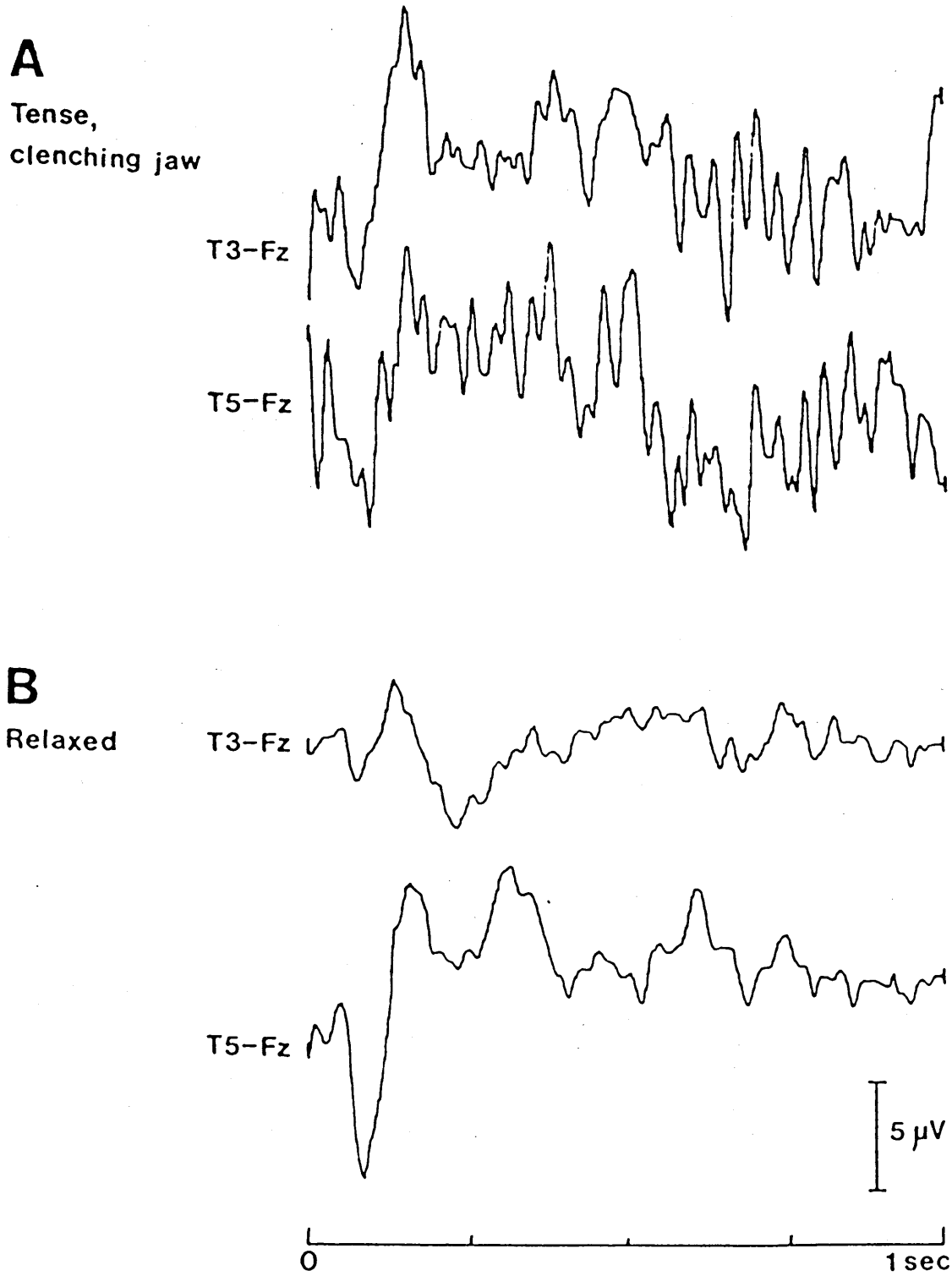


Fig 3:1 Myogenic activity. A and B show the same channels: T3, a mid temporal electrode and T5 situated over the posterior temporal region, both referred to Fz. In A the subject has become tense, in B relaxed. Calibration as shown, 16 sweeps averaged.

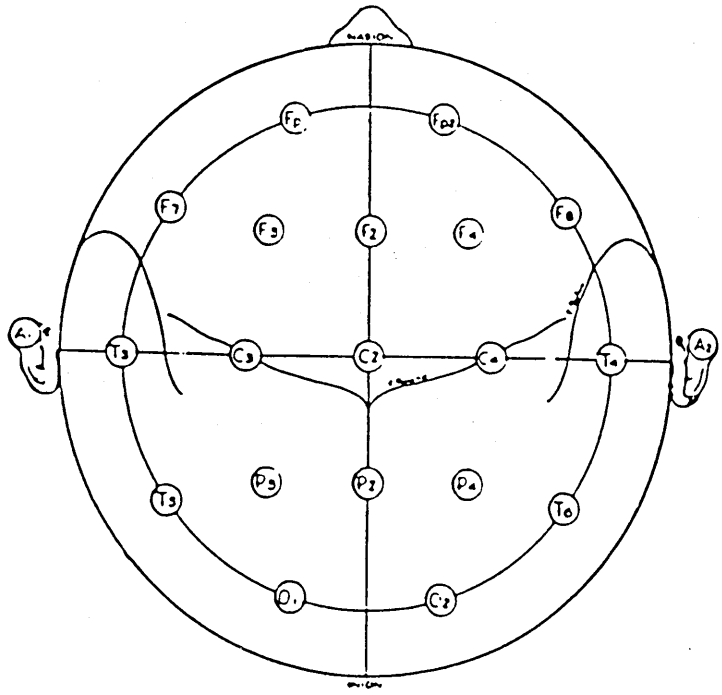


Fig 3:2. Diagram of the 10-20 system including the seven routine electrode positions over right (T6, P4 and O2) and left (T5, P3 and O1) posterior temporal, parietal and occipital areas and the mid-frontal reference, Fz.

each electrode with isopropyl alcohol. This procedure removes grease and desquamation, reducing skin resistance and improving tape adhesion. The hair was then separated and each electrode fixed in position with Blenderm surgical tape.

In three subjects eyeblinks and lateral eye movements were recorded from electrodes placed respectively above and below and on the inner and outer canthus of one eye (Fig 3:3). Because there is a steady potential difference in the order of 100 mV between the aqueous and vitreous humours of the eye (the former being positive with respect to the latter) a movement of the eyeball causes a potential field change that will be detected by electrodes in its vicinity. When the eyelids blink or the eyes are closed the eyeball makes a momentary upward deflection and an electrode on the forehead becomes electropositive with respect to one beneath. If an amplifier is connected between them the recording will show a large downward deflection (Nelligan, 1964). Lateral movements of the eyes will produce potential changes of opposite polarity at the frontotemporal electrodes on each side.

Recording electrodes were silver/ silver chlorided discs, 9 mm in diameter. Chloriding was carried out chemically, by immersing the electrodes in a solution of hypochlorite (Chloros). This method also allows simultaneous electrode sterilization, (Taylor, 1982; Jonkman and Ponsen, 1981.) The reason for chloriding silver electrodes is to render them reversible, enabling each electrode to present the same resistance to current flow in both directions i.e. the fluctuating E.E.G. potentials and the steady potential that arises at the interface between electrode and jelly. A reversible electrode has a relatively stable potential with respect to the contact medium and thus reduces low frequency artefacts caused by variation in the contact potential, as well as minimizing

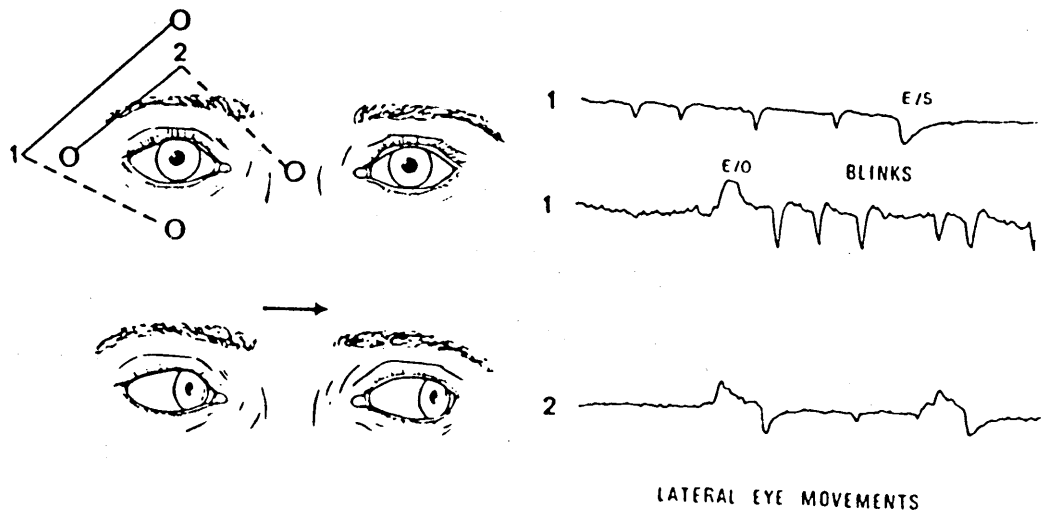


Fig 3:3. Recordings from electrodes placed (1) above and below the eye showing the effect of a blink, and (2) at the outer and inner canthus illustrating side to side eye movemnets.

distortion of the E.E.G. signal.

Following attachment with tape, inserting Neptic paste under each electrode and lightly scarifying the scalp with a blunted, sterilized needle reduced the resistance to below 5K ohms. Resistance was measured for each electrode on an S.L.E. meter, (model E.I.T.). It is desirable to minimize electrode resistance because if it remains high it can lead to a loss of voltage between the source and the recording apparatus, the latter also being dependent on the input resistance of the amplifiers. To reduce electrical interference an earth electrode was placed on the wrist. Differential preamplifier input stages are referred to an earth input and a balance between the two is maintained. True differential recording allows rejection of unwanted common mode signals.

At the end of a recording session, electrodes were singularly disconnected from the preamplifiers. The Blenderm tape was soaked with isopropyl alcohol to promote easier and less painful removal, the electrodes then eased off and the hair cleaned with gauze and combed back into position. Dry electrode jelly could be brushed out.

3. STIMULI

Seven different types of stimuli were used during the experiments, namely: a pattern reversal stimulus and slides of the following:- upright known faces, upright unknown faces, inverted known faces, inverted unknown faces, geometric designs and upright words. All the slides were copied from black and white originals. Those of known faces consisted of professionally taken photographs, obtained by writing to the press. The original unknown faces and the word series were borrowed from the Department of Neuropsychology, Radcliffe Infirmary. The geometric designs were taken from an art guide. The originals were photographed on to

Ilford FP4 film, using electronic flash, and developed for five minutes in Microphen Developer. The positives were printed on to Kodak 35 mm positive film and then mounted in Gepe 2 X 2 mounts. The slides were not matched for contrast due to the lengthy photographic process involved.

The conditions in each experiment were alternated between subjects to overcome any order effect. Right handed subjects, left handed subjects and patients viewed them in the following way :-

Expt.1	Right handed subjects	Slides of upright known faces Slides of upright unknown faces Slides of geometric designs Pattern reversal
Expt.2	Left handed subjects	Slides of upright known faces Slides of upright unknown faces Slides of geometric designs Pattern reversal
Expt.3	Right handed subjects	Slides of inverted known faces Slides of inverted unknown faces
Expt.4	Right handed subjects	Slides of upright words
Expt.5	Patient R.B.	As Experiment 1
Expt.6	Missile injured patients	Slides of upright known faces Slides of upright unknown faces Slides of goemetric designs Pattern reversal Slides of upright words Slides of inverted known faces

Known faces:

The stimuli consisted of 42 black and white slides of well known faces (members of the Royal Family, political leaders and celebrities); a few examples are shown in Fig 3:4 and a full list of names appears in Appendix B. (Exact details of the method of slide presentation are given in the Instrumentation section).

Unknown faces:

This series consisted of 64 black and white slides of faces of members of the Armed Forces, all unknown to the subjects. Examples appear in Fig 3:5. They were presented in the same way as the known slides.

Geometric designs:

The stimuli consisted of 64 black and white slides of complex shapes and designs; they were presented in the manner described for slides of faces. Most of the illustrations were taken from an art guide published by Thurston and Carraher, 1966. Examples appear in Fig 3:6. Only those shapes that in no way resembled letters were included to avoid any possibility of language interference.

Inverted known and unknown faces:

These slides were the same sets of faces previously used. They were merely placed upside down in the projector for presentation.

Words:

This series of slides consisted of 41 common words in everyday use, such as "car", "hand"," butterfly", "book" and "shoe", (Appendix C). Each word had been centred photographically (therefore appearing in the centre of the screen) and consisted of white letters on an even, black background. The height of each word subtended an angle of 2° 36' at the eye. As with the other types of slides, the words were presented for 2 seconds at random intervals and subjects were requested to fixate centrally.

Pattern Reversal:

The stimulus was a black and white checkerboard pattern (Fig 3:7) back projected on to a screen 110 cms in front of the subject. The pattern subtended an angle of 22° at the subject's eye, each square

KNOWN FACES

Fig 3.4. Examples of known faces: Humphrey Bogard, Harold Wilson, Charlie Drake, Margaret Thatcher, Mohammed Ali and Twiggy.

Fig 3:5. Examples of unknown faces, all members of the Armed Forces.

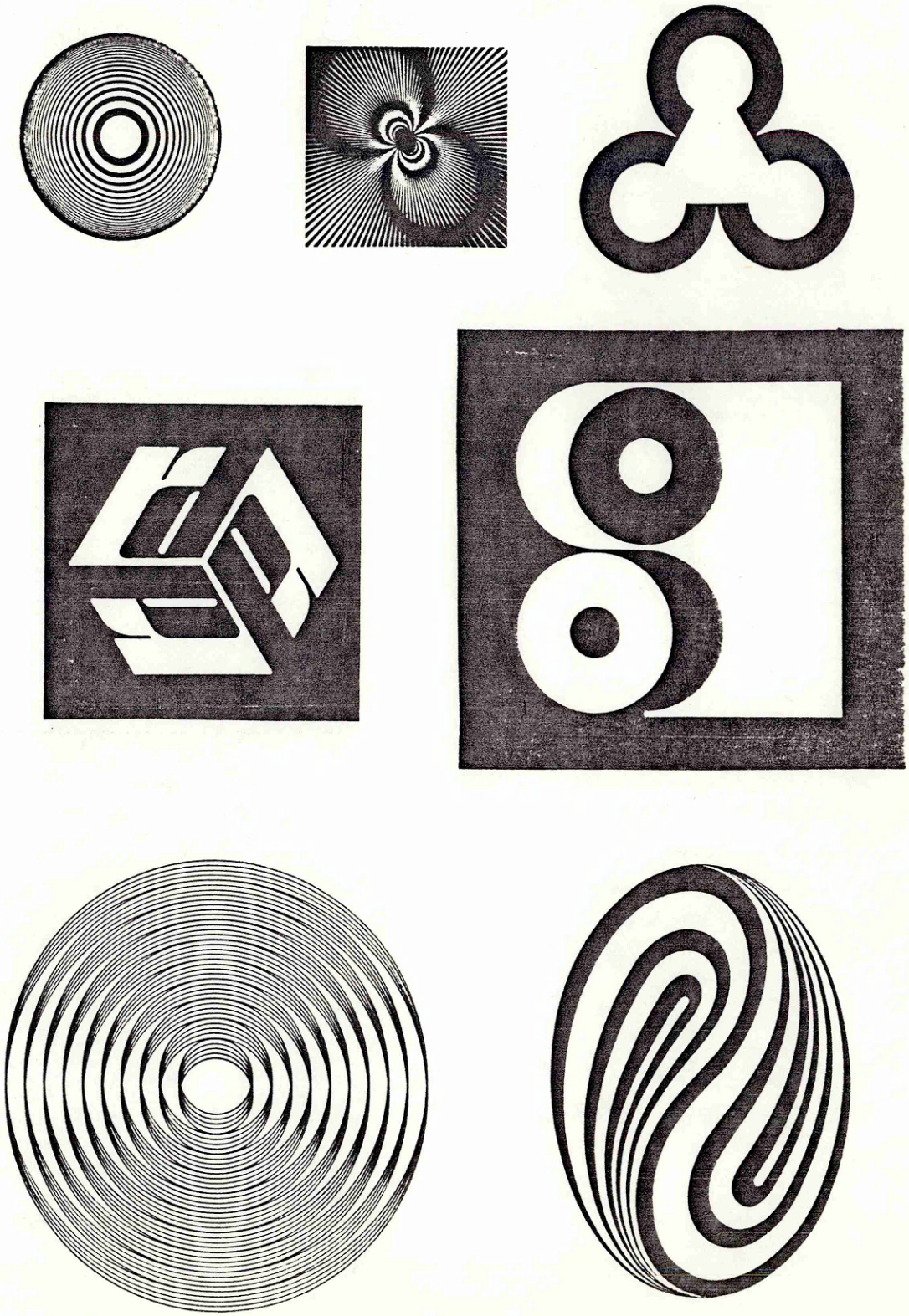


Fig 3:6. Examples of the complex geometric design slides.

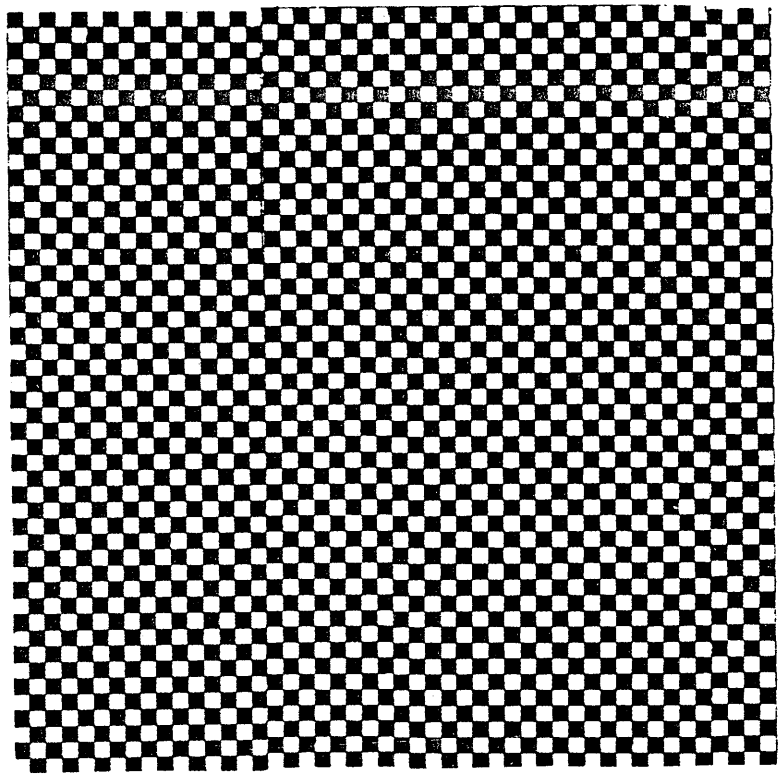


Fig 3:7 A representation of the black and white checkerboard pattern used as the pattern reversal stimulus; (not an exact replica).

subtending an angle of 48'. Sixty-four sweeps were averaged. (Details of the pattern movement are given under Instrumentation). Subjects were instructed to fixate on the centre of the screen.

4. INSTRUMENTATION AND RECORDING SYSTEM

A block diagram of the experimental set-up for presentation of slide stimuli is shown in Fig 3:8 and that for pattern reversal in Fig 3:9.

The equipment used included:-

6 Medelec pre-amplifiers

6 amplifiers

Gould Digital Storage Oscilloscope OS4000

Digitimer 4030 pulse generator

Texas Instruments 980B computer

Sigma Electronics Vector Graphic Display (V.D.U.)

Electronic Data Terminal, Silent 700 ASR (keyboard and printer)

Bryans high speed XY Recorder (plotter)

Kodak Carousel S-AV 2000 projector, modified with a short rise-time shutter

Forth Instruments Pulse generator

Visual Stimulator with Leitz Pradovit projector

Mirror amplifier

The surface electrodes were connected via the preamplifiers to the amplifiers, which had a gain of 50 and variable low and high frequency filters. Bandpass filtering of 0.1 Hz to 250 Hz (-3 dB points) was used. The amplified signals were fed to the Texas computer.

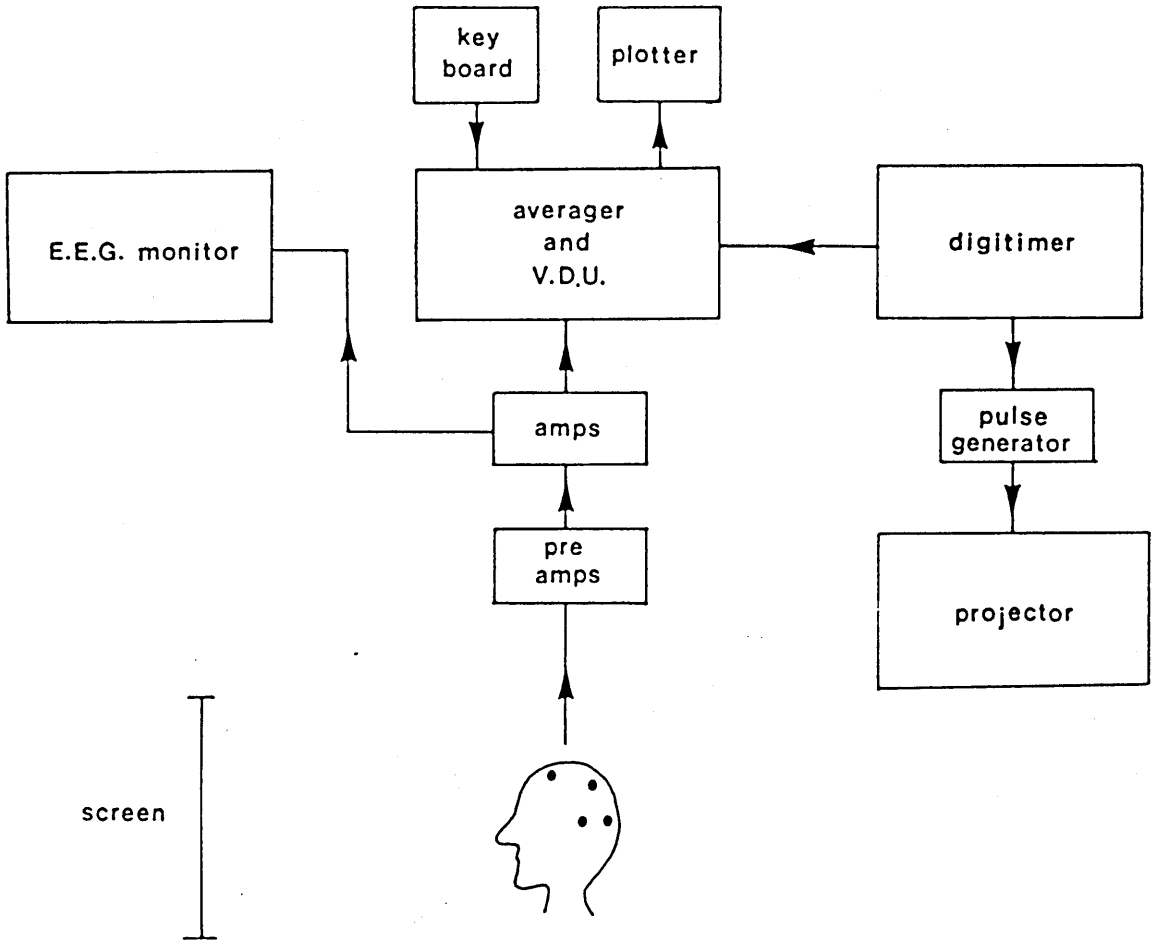


Fig 3:8. A block diagram representing the arrangement of equipment used for the presentation of slides.

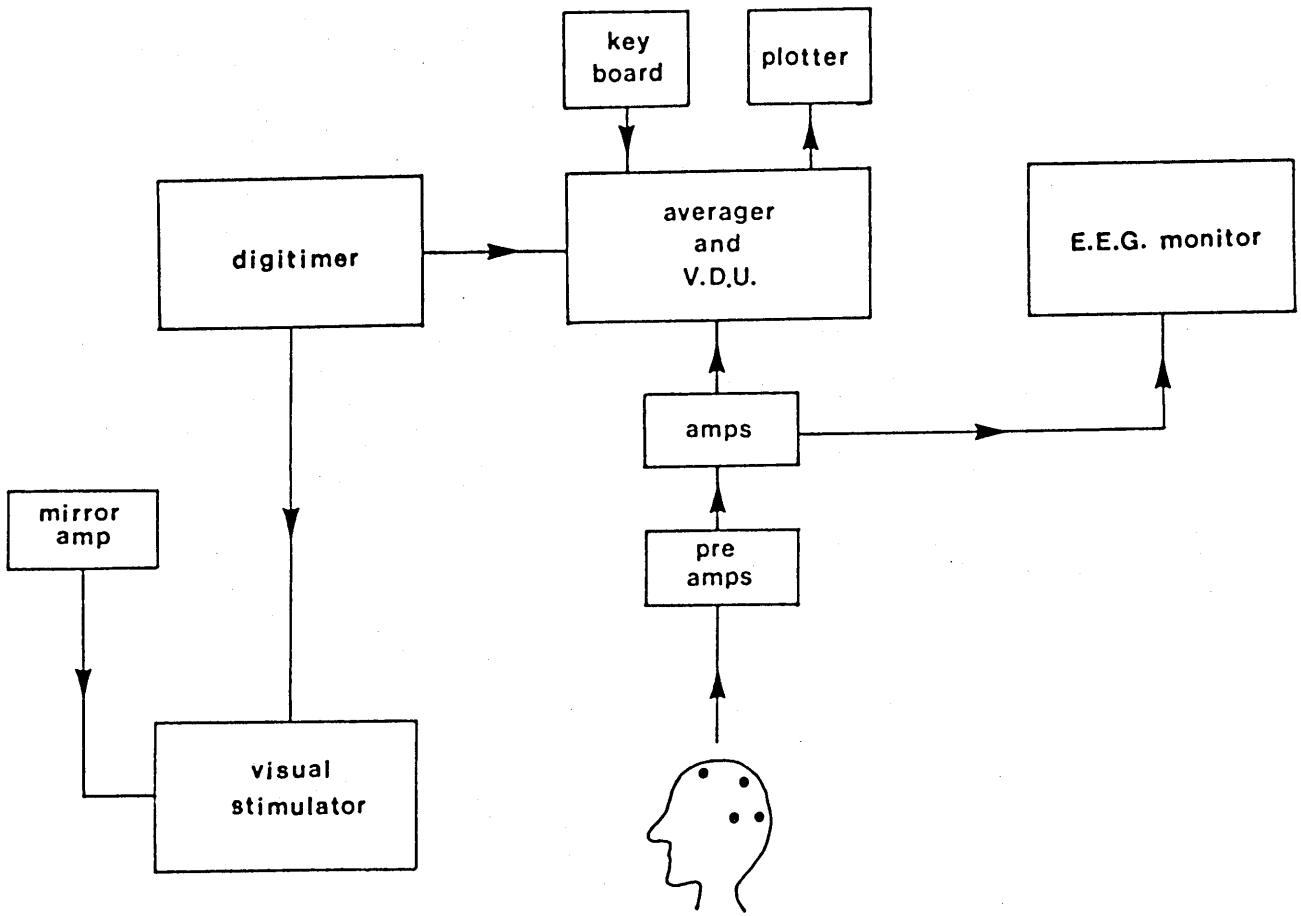


Fig 3:9. A block diagram of the equipment used for the pattern reversal stimulus.

Averaging:

The technique of signal averaging was used. This method allows the relatively small, recurrent signals evoked by the stimuli (but hidden amongst unwanted noise) to be displayed. Background noise consisted of the biological, spontaneous E.E.G. activity and electrical noise from the equipment and mains. As the evoked signal is in-phase across individual sweeps (because it is time locked to the stimulus) but random noise is not, the signal summates and the noise tends to cancel out.

Averaging was carried out by a program called Autoprog, written and installed by Mr. J. Wattam-Bell. Once loaded and initiated by instructions from the data terminal keyboard, Autoprog displayed a menu on the V.D.U., (Appendix D). From this menu one of sixteen functions could be chosen. These included a calibration procedure (CAL), a "start averaging" instruction (AV), an on-going E.E.G display, three preset averaging functions and a variable averaging format. Selection of the variable function allowed the user to define the sweep variables to be used, namely number of channels, number of sweeps, total sweep time and delay time. A calibration was carried out regularly using the CAL instruction. This provided a signal common to all channels and the amplifier gains could then be adjusted if necessary until all channels gave an equal deflection to the known signal.

After selecting the variable format, which was used for all experiments, the required sweep variables were stored by typing in the appropriate values on the data terminal keyboard. The following were chosen (except in preliminary experiments): number of channels = 6, number of sweeps = 42, 64 or 41 depending on the type of stimuli, sweep time = 1000 msec and delay time = 0.0 msec. The sweep time always differed slightly from that requested i.e. 1000.48 msec instead of 1000

msec. This effect was due to there being a finite number of data points and a finite resolution which results in a finite number of achievable sweep times (not necessarily a whole number of milliseconds). The Autoprog program calculated, displayed and used the sweep time nearest to that selected. For each sweep the computer sampled six simultaneous channels of 256 data points each, at a rate of approximately 256 points per second, with 12 bit precision.

Following insertion of these four variables, the E.E.G. function was selected to observe the on-going E.E.G. activity. This allowed simultaneous inspection of the six channels to check for electrode artefact and the level of myogenic activity prior to averaging. Once the recording appeared satisfactory, averaging began by selecting the AV function, the sweep being triggered by the Digitimer pulse generator.

Slide Presentation: Each slide was projected from a modified Kodak Carousel projector, for 2 seconds, on to a white screen positioned 110 cms in front of the subject, subtending an angle of 24°at the eye. The Digitimer start button (operated manually) triggered the sweep onset and simultaneously opened the fast acting shutter (rise time 2 msec) of the modified Kodak Carousel projector. This provided instantaneous projection of the slide on to the screen for 2 seconds and the slide then changed automatically. The slide presentation time was preset by the Forth Instruments pulse generator, which was driven by the Digitimer, and also connected to the shutter release and slide change of the projector, (Fig 3:10). The slides were presented at random intervals, ranging from 5 to 10 seconds. Subjects were instructed to fixate on the centre of the screen to minimise eye movement artefact and they were requested to try not to blink as the slide appeared. Throughout the actual presentation of

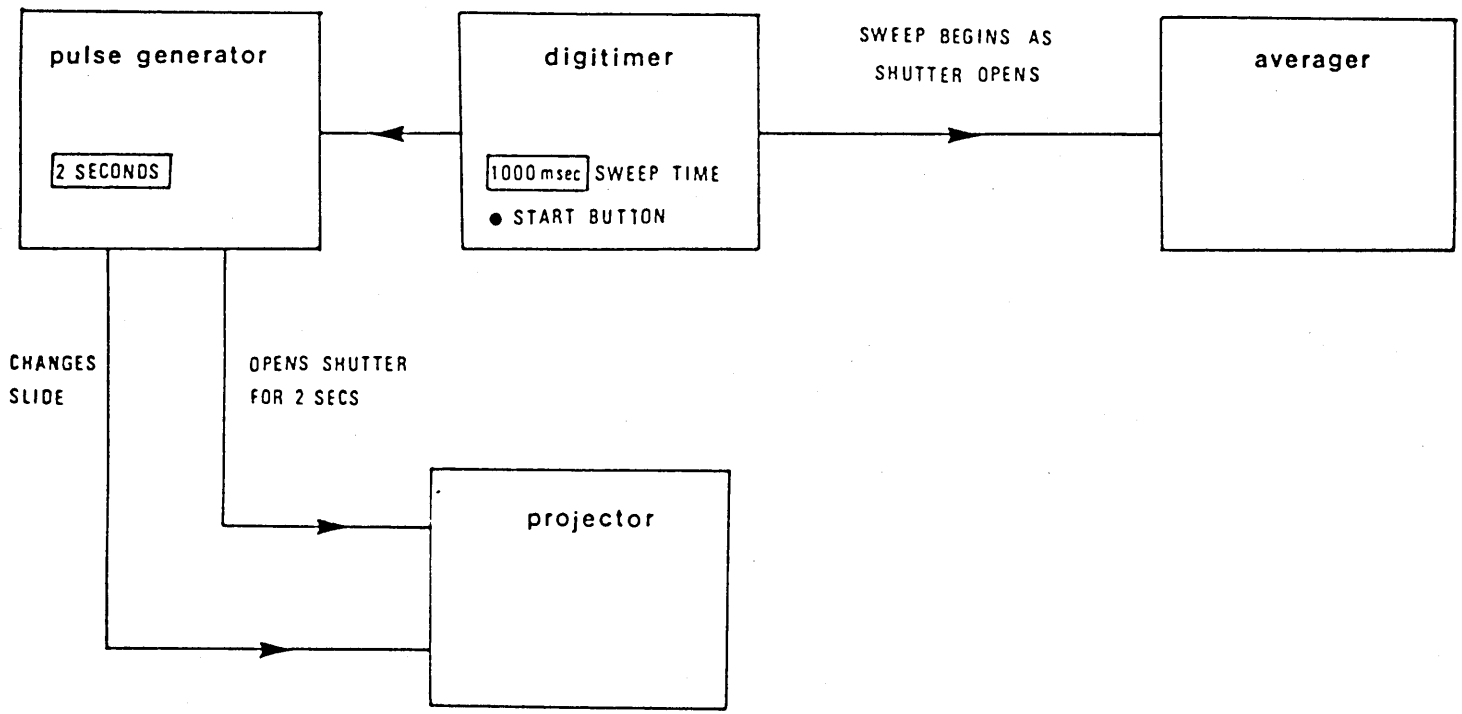


Fig 3:10. A block diagram showing the connections from the Digitimer to the pulse generator and averager which allowed simultaneous triggering of the slide presentation with the sweep onset and then a slide change.

slides and pattern reversal the room was darkened by purpose made black-out curtains, the only light visible being that from instrument indication lights.

Pattern reversal: The Digitimer triggered the sweep at the onset of the pattern displacement. A mirror projecting the black and white checkerboard slide (housed in the Leitz Pradovit projector) rotated through a small angle causing the pattern to move horizontally the width of one square every 1.5 seconds. This time was preset by the Digitimer and the amplitude of the mirror movement (i.e. one square) could be adjusted via the mirror amplifier.

During averaging, the on-going E.E.G. activity could be viewed (one channel at a time) on the Gould oscilloscope in order to monitor extraneous potentials (e.g. myogenic activity, blinks and interference). High voltage, unwanted extraneous activity was excluded from the average because the program incorporated an artefact rejection facility which was set to reject any sweep in which the input exceeded +/- 100 uV on any channel. Averaging ceased automatically once the required number of sweeps had been reached and each run was stored prior to processing.

Processing:

When averaging runs were finally completed (i.e. at the end of an experiment) the processing function was selected. This control loaded the program Proprog for printing and plotting the stored results. The Proprog menu, consisting of fifteen functions (e.g. filtering, scaling up, scaling down, print and plot) was displayed on the V.D.U. screen alongside the first stored average. Appendix E lists the Proprog functions. A three point moving average filter (frequency cut-off = 85 Hz) was applied to the data when necessary and if used sparingly had no

significant effect on amplitudes and latencies. The displayed average could be scaled up or down. Four cursors came into effect which could be moved transversely along the trace to measure four independent latencies and the corresponding amplitudes.

Once all stored averaging runs had been processed they were plotted on a Bryans XY recorder. The latencies and amplitudes corresponding to each plot (measured by the four cursors) were simultaneously printed out by the Data terminal. Each cursor gave only one latency read-out, common to all six channels. However, a potential to be measured often varied slightly in latency from one channel to another. Therefore, the majority of P100 and P300 latencies and amplitudes had to be calculated separately, at a later date, by hand. The amplitude of both P100 and P300 represented the peak to peak values, the potentials being measured from the upgoing, negative onset to the downward, positive deflection.

The direction in which the voltage fluctuations between a given pair of electrodes is reproduced depends upon the way in which they are connected to the input leads of an amplifier. Referring to these leads as black (Grid 1) and white (Grid 2), E.E.G. convention states that when the black lead becomes electro-negative with respect to the white, there will be an upward deflection. This practise enables the relative polarity of a particular discharge to be deduced and uniformly described. This convention has been adhered to and in the common reference (Fz) montage used in the majority of experiments, this single electrode (common to all channels) represents the white grid. In diagrams of bipolar montages, black leads are drawn as solid lines and white leads as broken lines.

5. STATISTICS

For normal subjects and patients the latencies and amplitudes of P100 and P300 from all electrode positions were measured by hand, then typed in and stored (according to the various conditions and handedness) on 8" floppy discs using the program Wordstar on a Research Machines 380Z computer. The age and sex of each subject were also recorded. This data was then changed into RT-11 format to enable Analyses of Variance to be carried out on a VAX computer at the Open University.

CHAPTER 4

PRELIMINARY EXPERIMENT

In the first introductory chapter it was suggested that by using electrophysiological techniques it might be possible to replicate the results obtained by other methods of a right hemisphere superiority for face processing. Initially, it was therefore necessary to investigate whether an evoked potential could be recorded in response to faces. If this proved possible, it was then essential to establish areas of maximum amplitude in order to simultaneously estimate the contribution from each hemisphere as well as the specific regions involved. The following preliminary study was designed to answer these questions.

Brief Procedure

Three right handed subjects (CP, CT and DS aged 21, 27 and 40 years respectively) took part. Seventeen electrodes of the 10-20 system were applied symmetrically to the scalp; seven over the right hemisphere, seven over the left and two at the midline, all referred to Fz (frontal, midline). Averaging was carried out consecutively from different sets of electrodes. Each subject viewed the known and unknown face slides as separate conditions. The peak to peak amplitude of P300 was then measured at all electrode sites for the two conditions.

Eye movement potentials were also simultaneously recorded during this experiment. A pair of electrodes was placed (i) above and below and (ii) on the outer and inner canthus of the right eye. The amplifier gain of these two channels was reduced to half (G20) or a quarter (G10) of the E.E.G. channels.

Results

In postcentral regions, evoked potentials were consistently recorded from the three subjects under both conditions. The typical response waveform (Fig 4:1) showed an initial positivity between approximately 80 and 120 msec and an upgoing negativity followed by a positivity around 260 - 320 msec. The form and latency of these two positive components corresponded to those of P100 and P300 as described in the literature. All subjects showed the area of largest amplitude for P300 occurring at T6, P4, O2, T5, P3 and O1 electrodes. As predicted, this component was maximal in the posterior temporal, parietal and occipital regions of each hemisphere. Fig 4:2, (a,b and c) illustrate these findings in subject C.P.

Due to the restricted number of amplifiers available, recordings could only be made from six channels simultaneously. It was therefore necessary to select three electrodes from the right hemisphere and three from the left for use in the main experiments. Accordingly, the above mentioned six electrodes, referred to Fz, became the routine placements in subsequent studies.

The eye movement recordings did not show any evidence of components occurring simultaneously with either P100 or P300 (Fig 4:3) and it was therefore decided not to include these electrodes routinely.

This preliminary study was obviously limited but provided promising results. Consequently, the first main experiment was set up to examine a larger series of subjects in order to try to replicate the above findings. The experiment was designed to obtain further evidence, both from the effects of brain lesions and from half field stimulation studies, that the right cerebral hemisphere is more involved in the

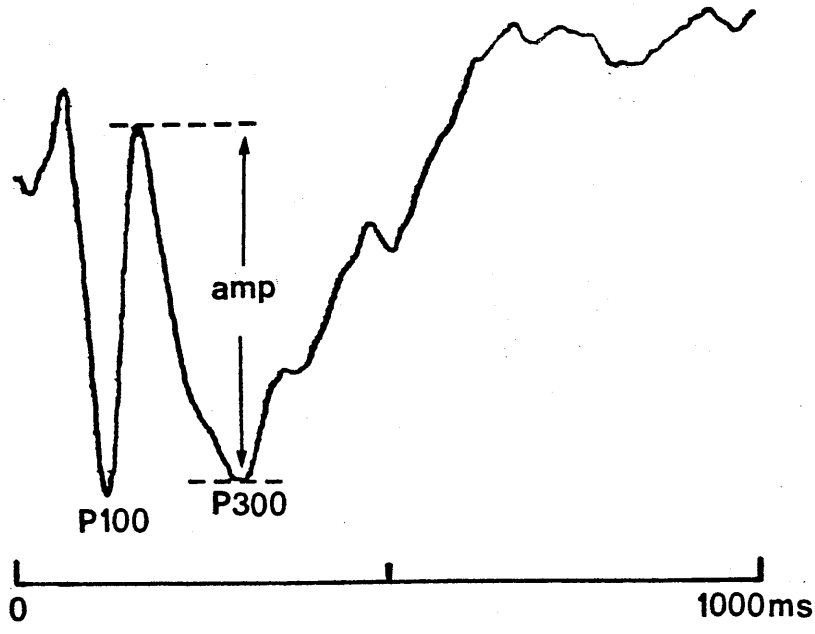


Fig 4:1. A typical evoked potential (average of 64 sweeps) showing P100, P300 and the measurement points for amplitude. Negativity upwards.

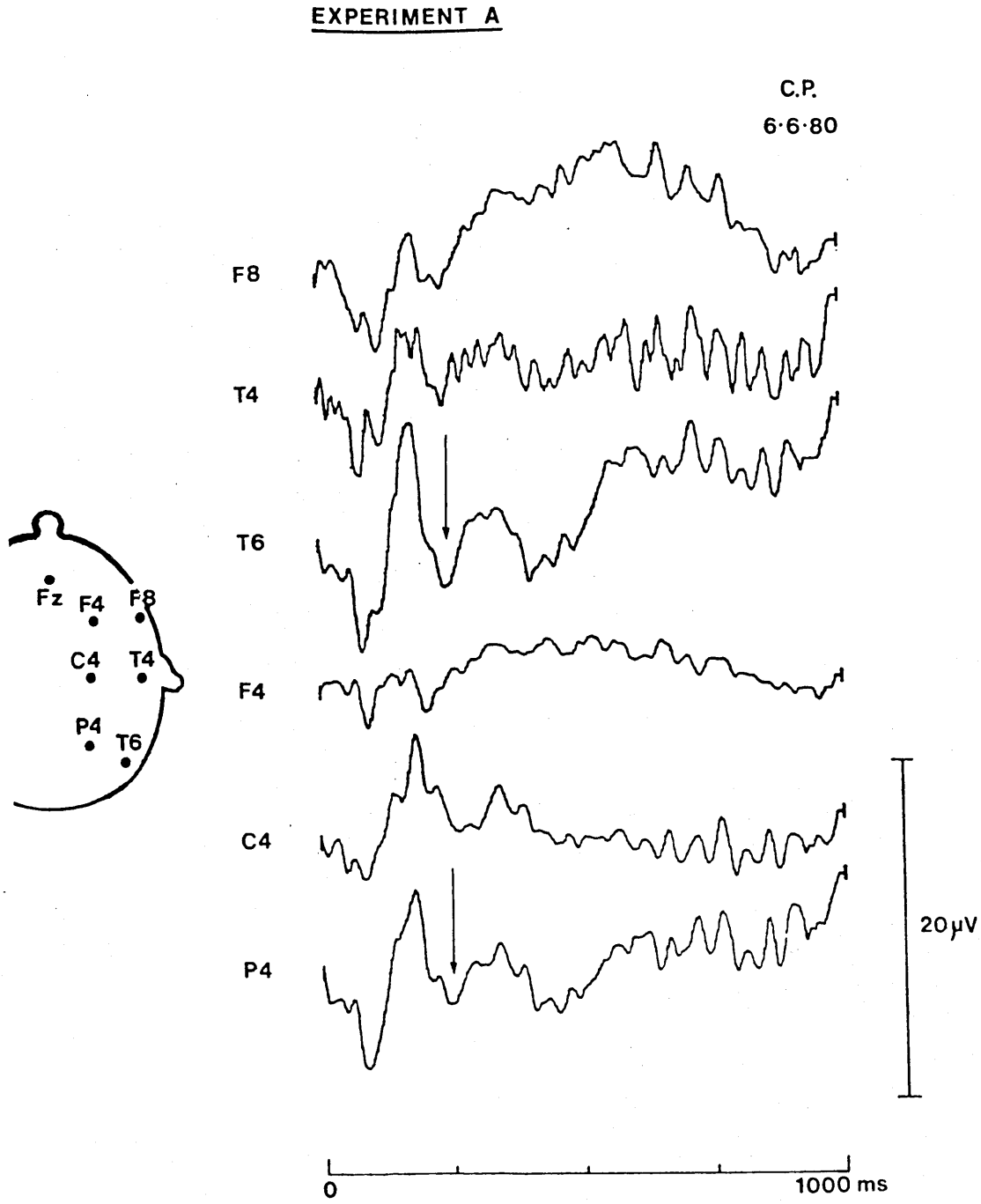


Fig 4:2; a, b and c. Consecutive recordings in subject C.P. from a total of sixteen electrodes each referred to Fz. The arrows indicate the sites of maximum amplitude for P300.

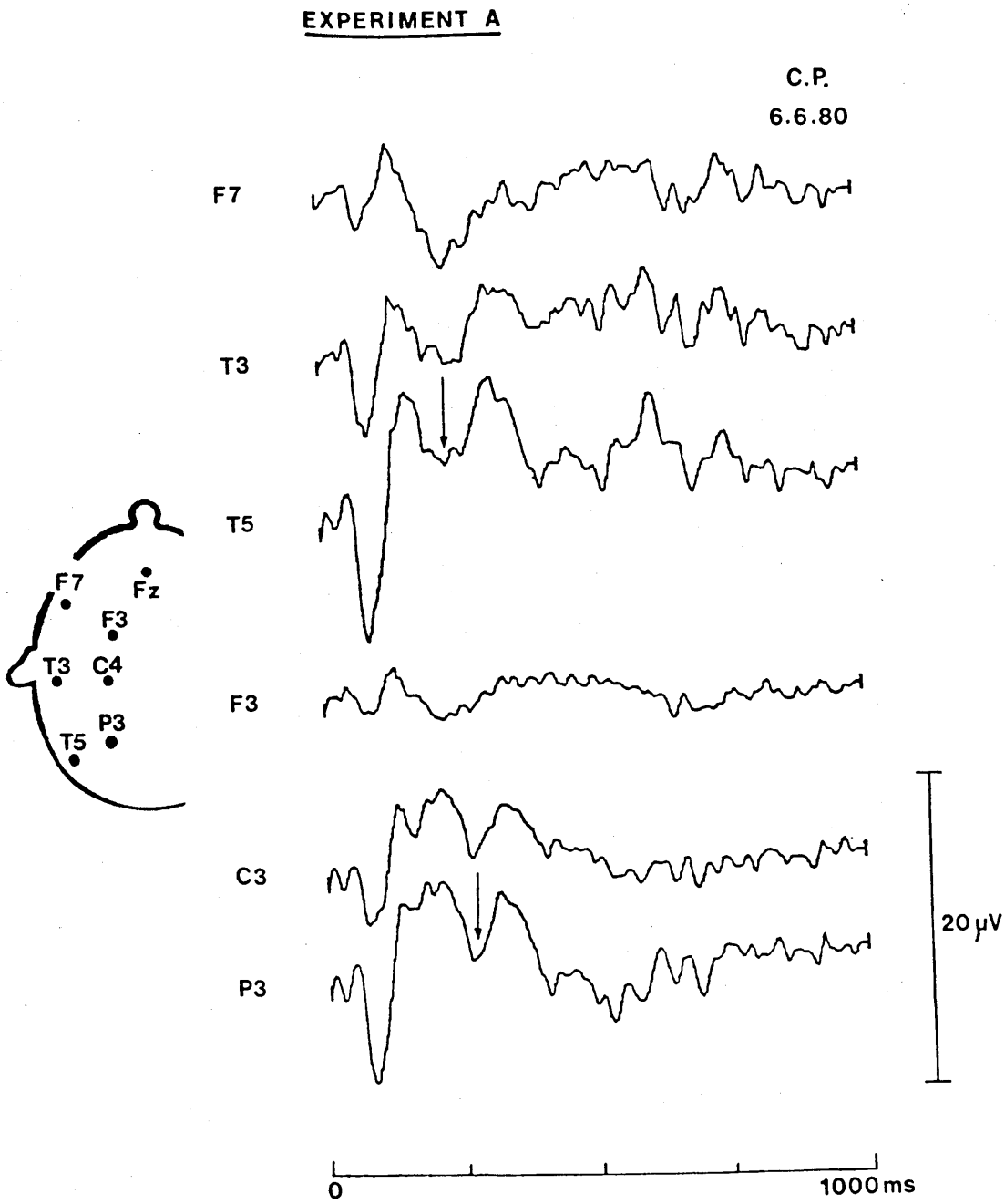

EXPERIMENT A
C.P.
6.6.80
F7
T3
T5
F3
C3
P3
F7
Fz
F3
T3
C4
P3
T5
20 µV
0
1000 ms

Fig 4:2 b

EXPERIMENT A

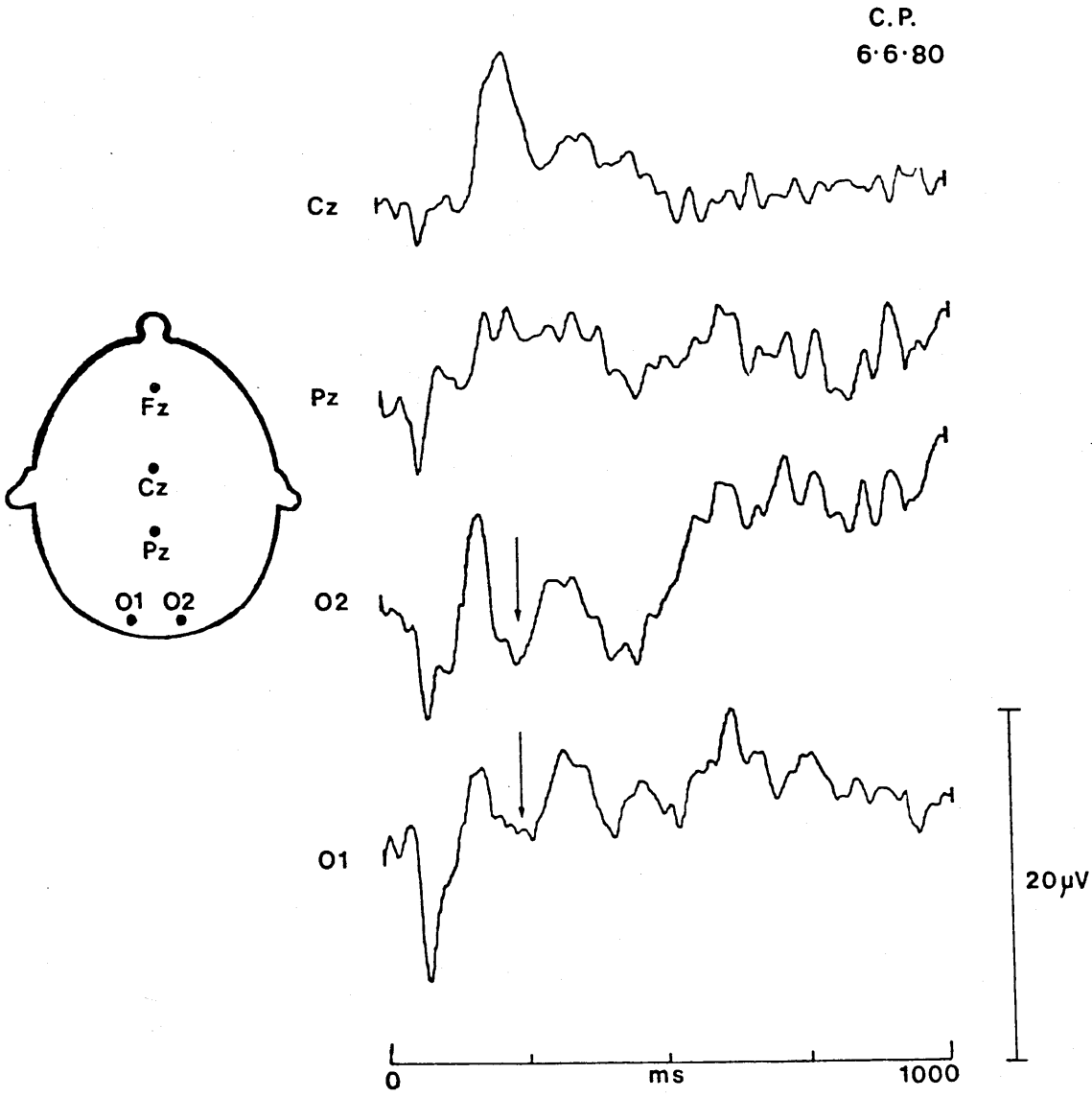


Fig 4:2 c

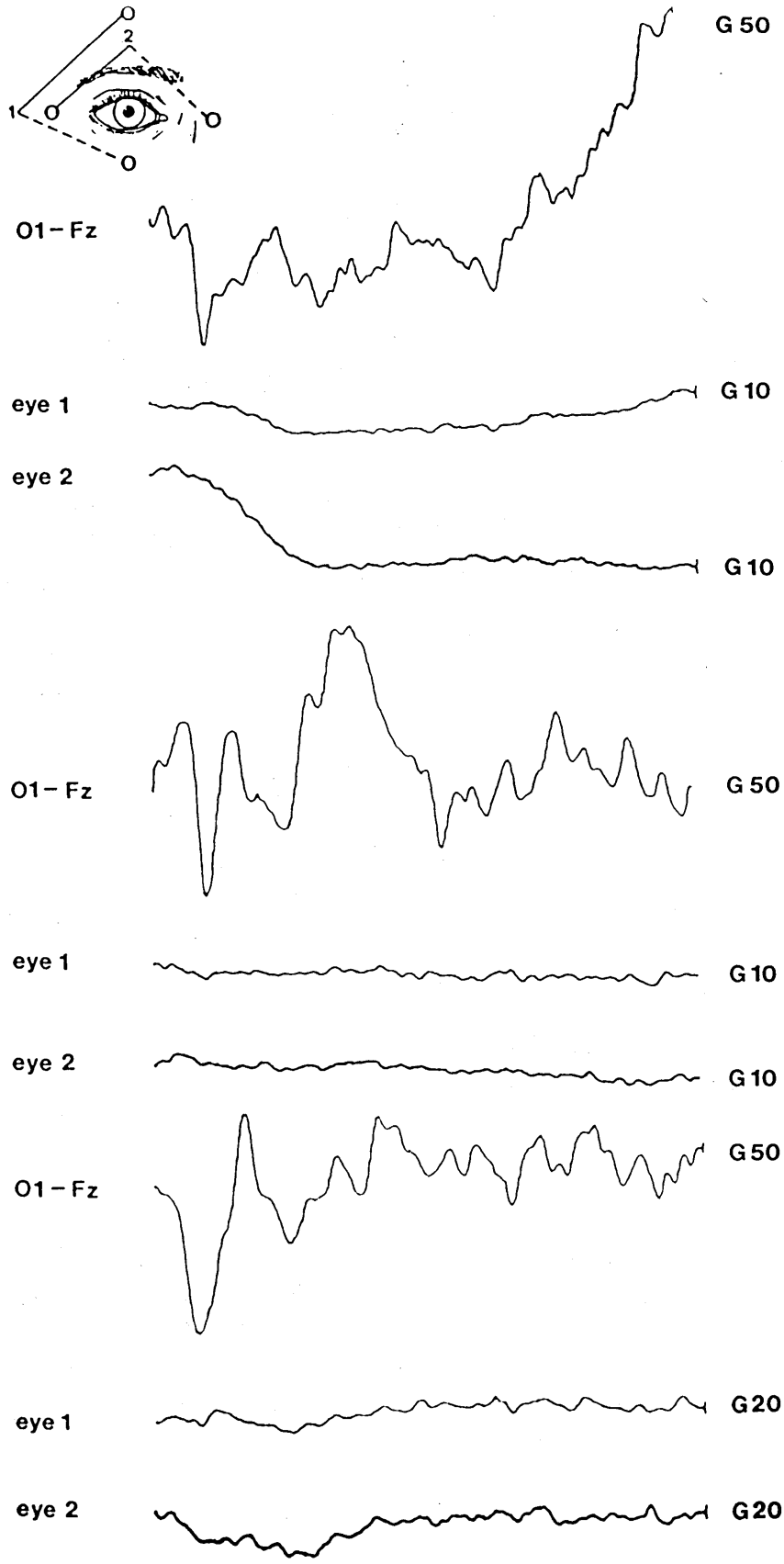


Fig 4:3 Eye movement potentials and an occipital lead recorded from 3 subjects. The eye electrodes do not show any components that occur simultaneously with P300. Sweep time 0-1000 ms, different gains as shown.

processing of faces than the left (in right handed individuals). If true, face stimuli might evoke a response with a right sided P300 amplitude superiority. But, it could be that all types of visual stimulation are processed asymmetrically, revealing, in a study designed to compare homologous hemisphere sites, a similar asymmetry to that proposed for slides of faces. Although there is no evidence for this assumption from studies of evoked potentials to flash and pattern reversal, the paper by Neville et al (1982), does suggest that P300 was largest at the right sided electrode for recognisable, meaningful slides. In order to check this possibility, two control conditions were presented in conjunction with the face stimuli; geometric designs were shown in order to observe the response to complex stimuli other than faces, and pattern reversal acted as a physical stimulus without cognitive content. If faces in particular, and not all visual stimuli, are specific to right hemisphere processing then they should show a right sided amplitude superiority greater than that shown by these control conditions.

The effect of recognition was also investigated by presenting two different series of face slides, those well known to the subjects and those completely unknown. Neville et al (1982) reported P300 to be clearly larger for slides that were recognised. However, their definition of recognisability relied on the slides being in focus as opposed to defocused, a factor which could lead to subsequent ambiguity in the interpretation of the results (as discussed earlier). The present study attempts to overcome this problem by showing two sets of faces, both of which have meaningful and complex properties but greatly differ in their ability to evoke recognition by the subject. Based on the results of Neville et al (1982), P300, in response to well known faces, should be larger than when elicited by unknown faces.

EXPERIMENT 1.

The evoked response to face and control stimuli in right handed subjects.

Brief Procedure

Thirty right handed controls, 15 males and 15 females were examined. Their ages ranged from 14 to 60 years, mean age 30.5 years. Each subject viewed four types of stimuli: known and unknown faces, geometric designs and pattern reversal. Forty-two sweeps were averaged for known faces and sixty-four sweeps for the other three conditions. Pattern reversal alternated once every 1.5 seconds. Slides of faces were shown during session 1, geometric designs and pattern reversal during session 2, at a later date. The two conditions presented at each of these sessions were alternated between subjects to overcome any order effect. Recordings were made from electrodes overlying the right and left posterior temporal, parietal and occipital regions, all referred to Fz.

Results

Evoked potentials were again consistently recorded from each subject at all electrode sites for the four conditions. The typical response showed the same waveform as that described in the preliminary study. Tables 4:4 and 4:5 illustrate (with the respective standard deviations) the mean latencies and amplitudes for P100 and P300 respectively at each electrode site, for the four types of stimuli.

The data from this experiment conform to a factorial analysis of variance (ANOVA) design, with one grouping factor (sex or age of

RIGHT HANDERS

KNOWN AND UNKNOWN FACES

GEOMETRIC DESIGNS AND PATTERN REVERSAL

P100 AMPLITUDES AND LATENCIES

TABLE 4:4

		T6	P4	O2	T5	P3	O1
KNOWN FACES	lat (msec)	117 (15.6)	117 (15.7)	116 (16.7)	114 (16.7)	115 (16.5)	115 (15.8)
	amp (uV)	7.8 (3.9)	7.5 (4.2)	11.7 (5.9)	7.2 (3.6)	7.1 (3.7)	11.6 (5.4)
UNKNOWN FACES	lat (msec)	118 (16.3)	117 (15.9)	117 (17.6)	117 (16.7)	116 (18.7)	118 (17.7)
	amp (uV)	8.1 (4.4)	7.7 (4.1)	12.7 (5.9)	6.8 (3.6)	6.4 (3.6)	11.6 (6.0)
GEOMETRIC DESIGNS	lat (msec)	93 (17.4)	92 (17.1)	91 (16.6)	90 (15.3)	89 (15.2)	90 (15.3)
	amp (uV)	7.9 (5.5)	8.1 (4.7)	12.1 (7.4)	7.0 (4.3)	6.4 (4.1)	11.3 (7.2)
PATTERN REVERSAL	lat (msec)	96 (10.9)	93 (10.2)	92 (7.7)	93 (9.8)	92 (8.8)	91 (5.8)
	amp (uV)	6.4 (3.8)	6.2 (3.9)	13.2 (7.2)	5.6 (3.2)	4.9 (3.2)	12.5 (6.8)

* Brackets indicate respective standard deviations

RIGHT HANDERS

TABLE 4:5

KNOWN AND UNKNOWN FACES

GEOMETRIC DESIGNS AND PATTERN REVERSAL

P300 AMPLITUDES AND LATENCIES

	T6	P4	O2	T5	P3	O1
KNOWN FACES	lat (msec) 291 (30.2) amp (μV) 20.3 (5.8)	293 (29.0) 14.6 (5.6)	290 (33.2) 21.9 (8.1)	289 (32.2) 17.2 (7.4)	292 (32.6) 12.5 (5.4)	292 (32.6) 19.1 (8.2)
UNKNOWN FACES	lat (msec) 292 (27.8) amp (μV) 19.7 (6.9)	293 (29.6) 15.0 (4.8)	291 (28.5) 21.1 (8.1)	289 (27.3) 17.7 (7.0)	289 (31.2) 13.1 (5.0)	290 (27.9) 18.6 (7.8)
GEOMETRIC DESIGNS	lat (msec) 279 (36.9) amp (μV) 13.8 (5.8)	278 (36.4) 12.2 (5.4)	271 (32.0) 14.9 (6.3)	277 (31.1) 13.1 (5.4)	272 (37.1) 11.2 (5.1)	266 (32.9) 14.2 (7.1)
PATTERN REVERSAL	lat (msec) 272 (52.6) amp (μV) 7.5 (3.9)	270 (50.7) 7.6 (4.1)	267 (50.5) 9.1 (4.9)	270 (48.3) 6.3 (3.5)	268 (49.1) 5.9 (3.4)	265 (47.2) 8.8 (5.1)

* Brackets indicate respective standard deviations

subject) and three within subject (repeated measure) factors as follows: i) side of recording (laterality), ii) site of recording (electrode positions) and iii) stimulus type (the four conditions). Analysis of Variance (ANOVA) was performed separately on each of the four dependent variables: P100 amplitude, P100 latency, P300 amplitude and P300 latency.

ANOVA: P100 amplitude

Table 4:6 and Fig 4:7 present the Analysis of Variance results for P100 amplitude; ($p < 0.05$ being regarded as significant in respect to the table of probabilities). There is a significant laterality effect, $F(1,28) = 15.9$, $p < .001$ which indicates a right greater than left P100 amplitude. This is a general effect as it does not interact with condition, $F(3,84) = 1.16$, $p > 0.3$, or electrode position, $F(2,56) = 1.63$, $p > 0.2$. The mean amplitude of all the right hemisphere electrodes (summed over the four conditions) was 9.13 uV and for the left hemisphere 8.19 uV. There is therefore an overall right greater than left P100 amplitude asymmetry in the order of 0.9 uV.

The position of electrodes also proved significant, $F(2,56) = 82.9$, $p < .001$, with the maximum amplitude occurring in occipital regions with all four conditions. This effect interacts with condition $F(6, 168) = 5.45$, $p < .001$. Fig 4:7 suggests that this finding is largely due to pattern reversal producing smaller P100 amplitudes (compared to the other three conditions) in temporal and parietal regions, but higher amplitude responses occipitally. The temporal electrodes (T6 and T5), the parietal electrodes (P4 and P3) and the occipital electrodes (O2 and O1) were each summed and the mean taken for the three conditions excluding pattern reversal, the values being 7.47 uV (temporal), 7.19 uV (parietal) and 11.84 uV (occipital). The corresponding pattern reversal

For text prior to page 104 reference should be made to Tables 4:6a, 4:9a, 4:11a and 4:15a. Values relating to the effects of sex and age are then given in the original Tables (4:6, 4:9, 4:11 and 4:15).

P100 AMPLITUDE Table 4:6a

ANOVA Table of probabilities for Experiment 1

Known and unknown faces, geometric designs and pattern reversal (right handers)

Source	Degrees of Freedom	F	Probability	
Condition	3	0.3238	0.8082	
Condition/Sex	3	2.5309	0.0626	
Error	84			
Laterality	1	15.9054	0.0004	*
Laterality/Sex	1	0.0361	0.8508	
Error	28			
Position	2	82.8981	0.0000	*
Position/Sex	2	4.5964	0.0142	
Error	56			
Condition/Lat	3	1.1610	0.3296	
Condition/Lat/Sex	3	1.2903	0.2831	
Error	84			
Condition/Position	6	5.4513	0.0000	*
Cond/Pos/Sex	6	3.8830	0.0012	
Error	168			
Laterality/Position	2	1.6267	0.2057	
Lat/Pos/Sex	2	0.4099	0.6657	
Error	56			
Cond/Lat/Pos	6	0.4220	0.8636	
Cond/Lat/Pos/Sex	6	1.4833	0.1867	
Error	168			

P100 AMPLITUDE

TABLE 4:6

ANOVA Table of probabilities for Experiment 1

Known and unknown faces, geometric designs and pattern reversal (right handers)

Source	Degrees of Freedom	F	Probability	
Sex	1	6.04	0.0216	
Age	2	2.60	0.0952	
Sex/Age	2	4.52	0.0217	
Error	24			
Condition	3	0.22	0.8790	
Condition/Sex	3	2.43	0.0725	
Condition/Age	6	0.65	0.6878	
Cond/Sex/Age	6	0.36	0.9026	
Error	72			
Laterality	1	14.63	0.0008	*
Laterality/Sex	1	0.02	0.8907	
Laterality/Age	2	0.71	0.5032	
Lat/Sex/Age	2	1.08	0.3566	
Error	24			
Condition/Laterality	3	1.11	0.3527	
Cond/Lat/Sex	3	1.61	0.1944	
Cond/Lat/Age	6	0.50	0.8044	
Cond/Lat/Sex/Age	6	1.76	0.1193	
Error	72			
Position	2	87.54	0.0000	*
Position/Sex	2	5.58	0.0066	*
Position/Age	4	1.80	0.1442	
Pos/Sex/Age	4	0.50	0.7363	
Error	48			
Condition/Position	6	5.80	0.0000	*
Cond/Pos/Sex	6	3.45	0.0032	*
Cond/Pos/Age	12	2.15	0.0172	*
Cond/Pos/Sex/Age	12	1.26	0.2481	
Error	144			
Laterality/Position	2	2.04	0.1413	
Lat/Pos/Sex	2	0.34	0.7149	
Lat/Pos/Age	4	1.36	1.2619	
Lat/Pos/Sex/Age	4	2.28	0.0745	
Error	48			
Condition/Lat/Pos	6	0.41	0.8714	
Cond/Lat/Pos/Sex	6	1.40	0.2203	
Cond/Lat/Pos/Age	12	0.75	0.7001	
Cond/Lat/Pos/Sex/Age	12	0.80	0.6487	
Error	144			

P100 AMPLITUDE

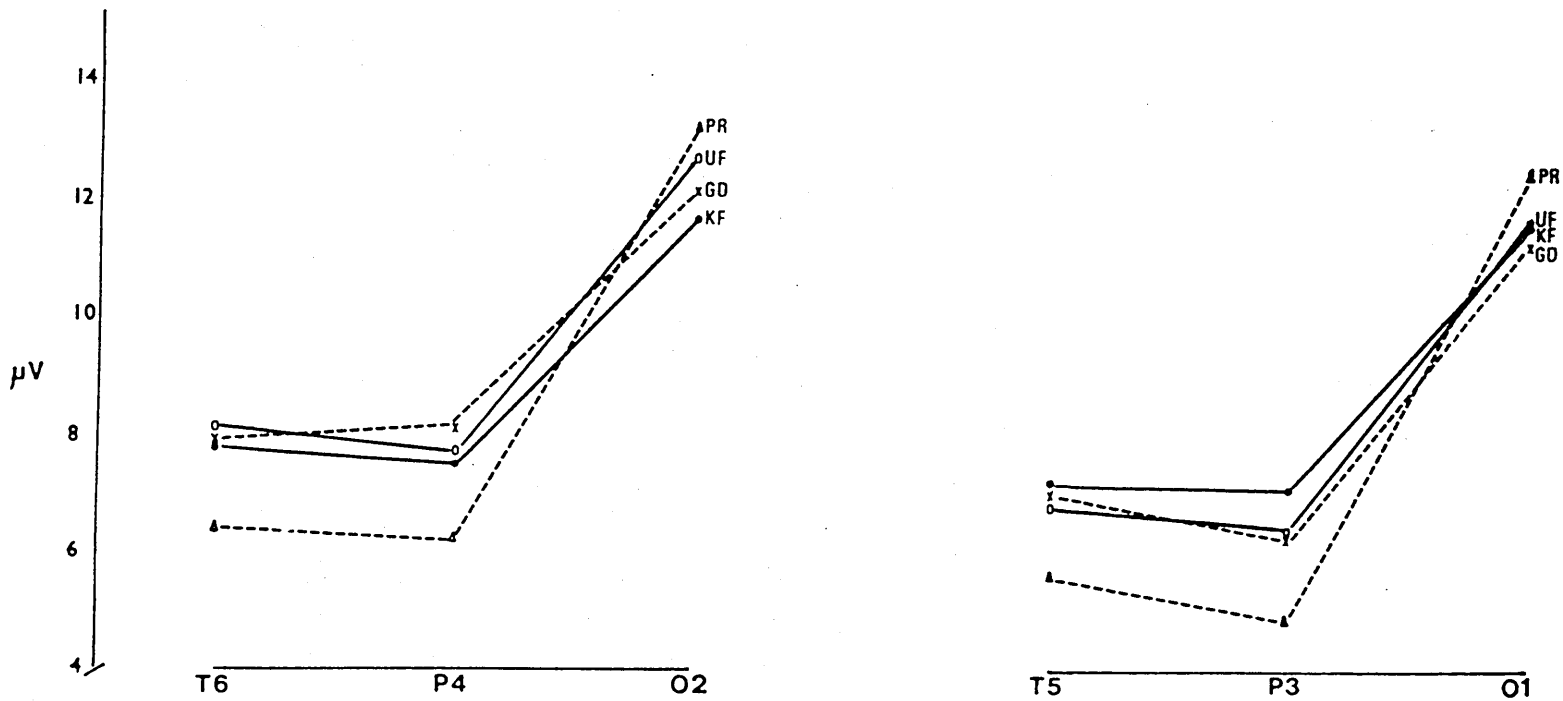


Fig. 4:7. Amplitude (uV) of P100 plotted at the six electrode positions, for the four stimulus conditions. For this and all subsequent illustrations KF = known faces, UF = unknown faces, GD = geometric designs and PR = pattern reversal.

TABLE 4:8 P100 AMPLITUDE Effect of Position and Condition

	Temporal	Parietal	Occipital
KNOWN FACES	7.49	7.30	11.67
UNKNOWN FACES	7.48	7.03	12.13
GEOMETRIC DESIGNS	7.46	7.24	11.71
PATTERN REVERSAL	6.03	5.57	12.83

amplitudes were 6.03 uV, 5.57 uV and 12.83 uV, (see Table 4:8). Therefore, during pattern reversal the temporal and parietal regions were respectively 1.4 uV and 1.6 uV smaller and the occipital area 1.0 uV larger than the mean P100 amplitude of the other three conditions.

ANOVA: P100 latency.

Table 4:9 shows the Analysis of Variance results for P100 latency and Fig 4:10 illustrates the mean P100 latencies at the six electrode sites for the four conditions. There is a significant effect with condition, $F(3,84) = 30.8$, $p < .0001$, due to P100 being 25 ms earlier with geometric designs and pattern reversal than with known and unknown faces, at all electrode sites. The laterality effect is also significant, $F(1,28) = 14.03$, $p < .001$; the mean P100 latency of the right side (over all four conditions combined) being 104.8 ms and for the left 103.4 ms. The right hemisphere therefore generally responds 1.4 ms slower than the left side. The effect of position is just significant, $F(2,56) = 3.5$, $p < .05$; this appears to be due to P100 occurring slightly later at the temporal electrodes than at the other two regions. There were no other significant results.

ANOVA: P300 amplitude.

Table 4:11 shows the ANOVA probabilities and the graph Fig 4:12 displays the mean P300 amplitudes for the four conditions at each electrode site. The effect of condition is significant, $F(3,84) = 50.0$, $p < .001$; this appears to be due to P300 amplitudes being generally larger in response to known and unknown faces than to geometric designs, which in turn elicited larger responses than pattern reversal. The amplitude of P300 was also significantly larger over the right hemisphere compared to the left (laterality effect $F(1,28) = 19.4$, $p < .01$), the mean right

P100 LATENCY Table 4:9 a

ANOVA Table of probabilities for Experiment 1.

Known and unknown faces, geometric designs and pattern reversal (right handers).

Source	Degrees of freedom	F	Probability	
Condition	3	30.7600	0.0000	*
Condition/Sex	3	1.1424	0.3368	
Error	84			
Laterality	1	14.0290	0.0008	*
Laterality/Sex	1	0.0774	0.7829	
Error	28			
Position	2	3.5000	0.0370	*
Position/Sex	2	1.3258	0.2738	
Error	56			
Condition/Lat	3	0.8029	0.4957	
Cond/Lat/Sex	3	2.9347	0.0381	
Error	84			
Condition/Position	6	1.2985	0.2605	
Cond/Pos/Sex	6	0.1998	0.9765	
Error	168			
Laterality/Position	2	2.5818	0.0846	
Lat/Pos/Sex	2	1.3091	0.2782	
Error	56			
Cond/Lat/Pos	6	0.2286	0.9669	
Cond/Lat/Pos/Sex	6	1.1431	0.3396	
Error	168			

P100 LATENCY TABLE 4:9

ANOVA Table of probabilities for Experiment 1

Known and unknown faces, geometric designs and pattern reversal (right handers)

Source	Degrees of Freedom	F	Probabilities	
Sex	1	6.41	0.0183	
Age	2	0.29	0.7532	
Sex/Age	2	0.12	0.8885	
Error	24			
Condition	3	28.19	0.0000	*
Condition/Sex	3	1.14	0.3371	
Condition/Age	6	0.36	0.9016	
Cond/Sex/Age	6	1.79	0.1123	
Error	72			
Laterality	1	13.49	0.0012	*
Laterality/Sex	1	0.02	0.8855	
Laterality/age	2	0.87	0.4326	
Lat/Sex/Age	2	0.05	0.9551	
Error	24			
Condition/Laterality	3	0.76	0.5219	
Cond/Lat/Sex	3	2.68	0.0531	
Cond/Lat/Age	6	0.67	0.6717	
Cond/Lat/Sex/Age	6	0.32	0.9231	
Error	72			
Position	2	3.31	0.0448	*
Position/Sex	2	1.49	0.2351	
Position/Age	4	1.28	0.2921	
Pos/Sex/Age	4	0.31	0.8730	
Error	48			
Condition/Position	6	1.11	0.3590	
Cond/Pos/Sex	6	0.12	0.9939	
Cond/Pos/Age	12	0.57	0.8663	
Cond/Pos/Sex/Age	12	0.50	0.9148	
Error	144			
Laterality/Position	2	2.70	0.0772	
Lat/Pos/Sex	2	1.17	0.3185	
Lat/Pos/Age	4	0.17	0.9539	
Lat/Pos/Sex/Age	4	0.35	0.8410	
Error	48			
Condition/Lat/Pos	6	0.18	0.9814	
Cond/Lat/Pos/Sex	6	0.98	0.4438	
Cond/Lat/Pos/Age	12	0.61	0.8337	
Cond/Lat/Pos/Sex/Age	12	0.62	0.8237	
Error	144			

P 100 LATENCY

TABLE 4:10

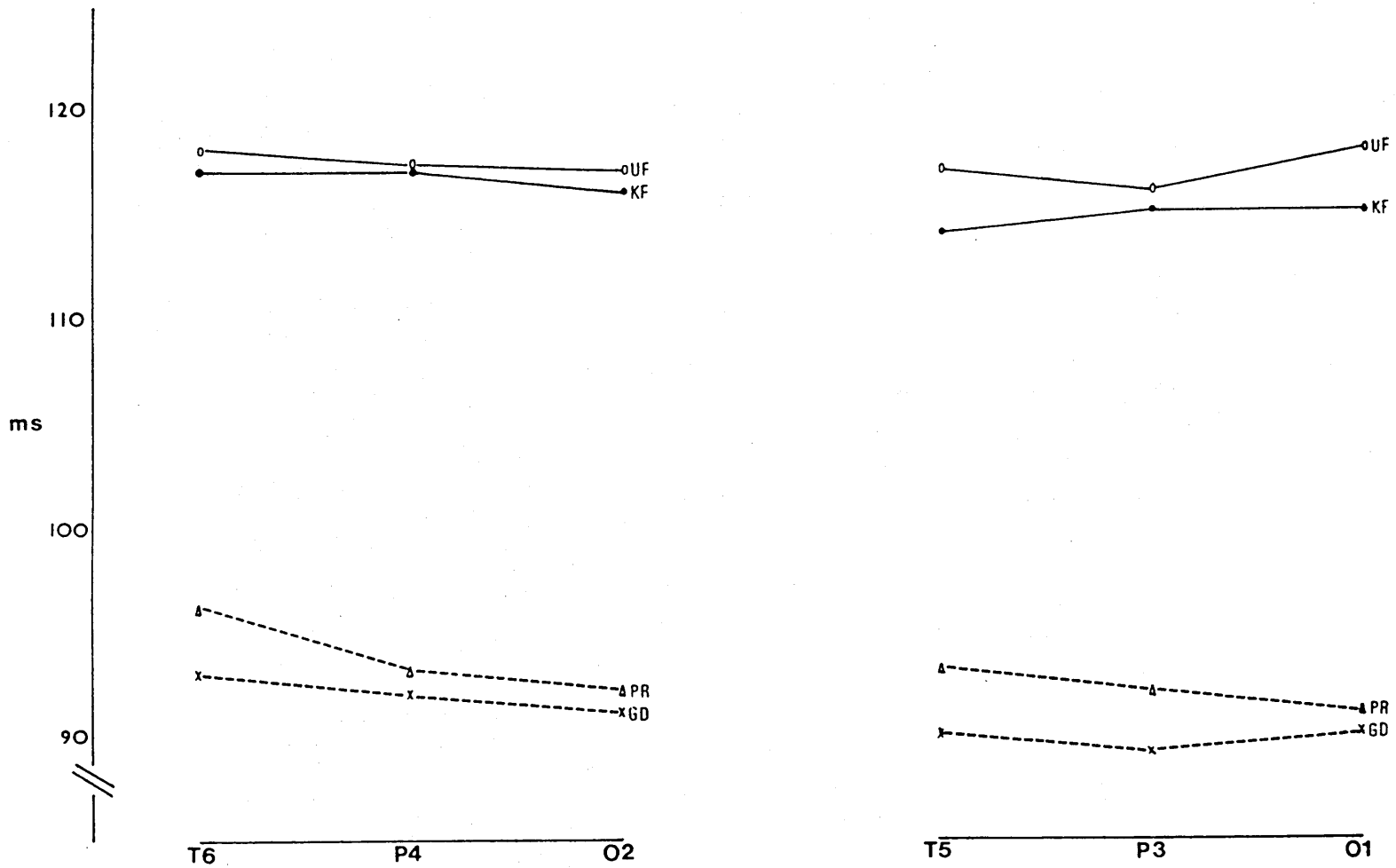


Fig 4:10 Latency (ms) of P100 plotted at the 6 electrode sites during the four conditions.

P300 AMPLITUDE

Table 4:11a

ANOVA Table of probabilities for Experiment 1.

Known and unknown faces, geometric designs and pattern reversal (right handers).

Source	Degrees of freedom	F	Probability
Condition	3	50.0434	0.0000 *
Condition/Sex	3	0.6327	0.5960
Error	84		
Laterality	1	19.4585	0.0001 *
Laterality/Sex	1	0.2641	0.6114
Error	28		
Position	2	44.6883	0.0000 *
Position/Sex	2	2.8707	0.0650
Error	56		
Condition/Lat	3	6.6899	0.0004 *
Cond/Lat/Sex	3	1.1876	0.3195
Error	84		
Condition/Position	6	12.7061	0.0000 *
Cond/Pos/Sex	6	1.6330	0.1409
Error	168		
Laterality/Position	2	0.2709	0.7637
Lat/Pos/Sex	2	0.9189	0.4049
Error	56		
Cond/Lat/Pos	6	2.4630	0.0262
Cond/Lat/Pos/Sex	6	1.3517	0.2371
Error	168		

P300 AMPLITUDE TABLE 4:11

ANOVA Table of probabilities for Experiment 1

Known and unknown faces, geometric designs and pattern reversal (right handers)

Source	Degrees of Freedom	F	Probability	
Sex	1	1.48	0.2388	
Age	2	0.70	0.5103	
Sex/Age	2	3.08	0.0693	
Error	19			
Condition	3	50.33	0.0000	*
Condition/Sex	3	0.33	0.8023	
Condition/Age	6	6.19	0.0000	*
Cond/Sex/Age	6	1.44	0.2138	
Error	57			
Laterality	1	13.20	0.0018	*
Laterality/Sex	1	0.00	0.9604	
Laterality/Age	2	0.64	0.5372	
Lat/Sex/Age	2	0.33	0.7227	
Error	19			
Condition/Laterality	3	4.87	0.0044	*
Cond/Lat/Sex	3	0.97	0.4120	
Cond/Lat/Age	6	0.44	0.8458	
Cond/Lat/Sex/Age	6	0.69	0.6558	
Error	57			
Position	2	39.26	0.0000	*
Position/Sex	2	1.37	0.2657	
Position/Age	4	1.65	0.1814	
Position/Sex/Age	4	2.16	0.0923	
Error	38			
Conditon/Position	6	10.04	0.0000	*
Cond/Pos/Sex	6	2.12	0.0565	
Cond/Pos/Age	12	1.30	0.2277	
Cond/Pos/Sex/Age	12	1.07	0.3957	
Error	114			
Laterality/Position	2	0.08	0.9227	
Lat/Pos/Sex	2	0.27	0.7684	
Lat/Pos/Age	4	0.67	0.6176	
Lat/Pos/Sex/Age	4	0.92	0.4602	
Error	38			
Condition/Lat/Pos	6	1.90	0.0862	
Cond/Lat/Pos/Sex	6	1.15	0.3391	
Cond/Lat/Pos/Age	12	0.64	0.8048	
Cond/Lat/Pos/Sex/Age	12	0.55	0.8778	
Error	114			

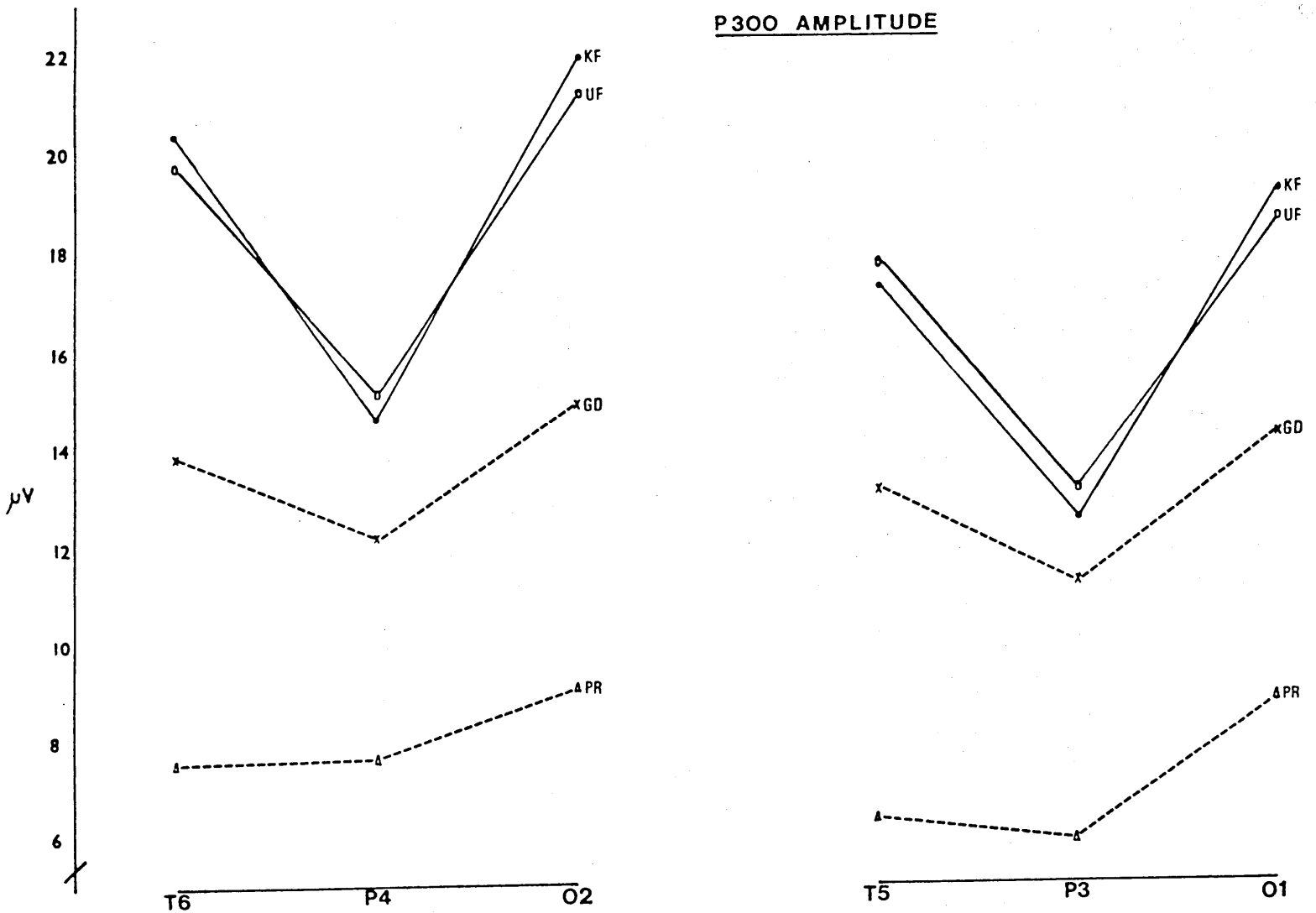


Fig 4:12 Amplitude (uV) of P300 plotted at the six electrode positions for the four stimulus conditions.

sided amplitude being 14.8 uV and the left 13.2 uV. This laterality effect interacts with condition, $F(3,84) = 6.69$, $p < .001$. Table 4:13 shows the mean P300 amplitudes for right and left hemispheres for each of the four conditions. The larger right sided P300 amplitude does appear as a general overall effect but the mean right hemisphere superiority of 2.32 uV with the face conditions is significantly greater than the right/left difference (0.92 uV) found by other stimuli. The laterality x electrode position result of $F(2,56) = 0.27$, $p = 0.76$ and the laterality x electrode position x condition interaction, $F(6,168) = 2.46$, $p = 0.02$ both proved non-significant, so the right hemisphere superiorities reported above were reflected equally at all electrodes.

The effect of electrode position was also significant, $F(2,56) = 44.69$, $p < .0001$. This is due to P300 amplitudes being consistently larger in occipital and temporal regions than parietally, as shown in Table 4:14. This result interacted with condition, $F(6,168) = 12.71$, $p < .0001$, the effect being much more marked with face stimuli.

ANOVA: P300 latency.

Table 4:15 gives the ANOVA probabilities and Fig 4:16 displays the mean P300 latencies for the four conditions at each electrode site. The laterality effect proved non-significant, $F(1,28) = 3.15$, $p = 0.08$. Therefore, in Table 4:17 right and left sided electrodes have been taken together to show the relationship between the four conditions and the different electrode positions.

The effect of condition was significant, $F(3,84) = 8.61$, $p < .001$. From Table 4:17 it is clear that P300 with geometric designs and pattern reversal occurred earlier (10-20 ms and 20-25 ms respectively) than during known and unknown face conditions. This effect was symmetrical as

TABLE 4:13 P300 AMPLITUDE Effect of Laterality and Condition

	Right hemisphere	Left hemisphere	Right/Left difference
KNOWN FACES	18.95	16.29	2.66
UNKNOWN FACES	18.48	16.50	1.98
			$\bar{X}$ = 2.32
GEOMETRIC DESIGNS	13.64	12.85	0.79
PATTERN REVERSAL	8.05	6.99	1.06
			$\bar{X}$ = 0.92
Mean of all conditions	14.78	13.16	

P300 amplitude from right and left hemispheres under the four separate conditions. Amplitude difference between hemispheres is shown on the right hand side.

TABLE 4:14 P300 AMPLITUDE Effect of Position and Condition

	Temporal	Parietal	Occipital
KNOWN FACES	18.78	13.56	20.51
UNKNOWN FACES	18.70	13.91	19.84
GEOMETRIC DESIGNS	13.48	11.72	14.54
PATTERN REVERSAL	6.88	6.73	8.95

P300 amplitude at the three recording positions (irrespective of hemisphere) under the four stimulus conditions.

ANOVA Table of probabilities for Experiment 1.

Known and unknown faces, geometric designs and pattern reversal (right handers).

Source	Degrees of freedom	F	Probability
Condition	3	8.6081	0.0000 *
Condition/Sex	3	0.2574	0.8558
Error	84		
Laterality	1	3.1509	0.0868
Laterality/Sex	1	0.0895	0.7670
Error	28		
Position	2	5.7208	0.0055 *
Position/Sex	2	3.3057	0.0440
Error	56		
Condition/lat	3	0.4098	0.7464
Cond/Lat/Sex	3	3.2308	0.0264
Error	84		
Condition/Position	6	3.7441	0.0016 *
Cond/Pos/Sex	6	2.0801	0.0581
Error	168		
Laterality/Position	2	0.3544	0.7031
Lat/Pos/Sex	2	0.5421	0.5846
Error	56		
Cond/Lat/Pos	6	0.4467	0.8465
Cond/Lat/Pos/Sex	6	0.1971	0.9773
Error	168		

P300 LATENCY TABLE 4:15

ANOVA Table of probabilities for Experiment 1

Known and unknown faces, geometric designs and pattern reversal (right handers)

Source	Degrees of Freedom	F	Probability	
Sex	1	6.55	0.0192	
Age	2	1.05	0.3697	
Sex/Age	2	0.81	0.4610	
Error	19			
Condition	3	2.84	0.0458	*
Condition/Sex	3	1.66	0.1869	
Condition/Age	6	0.53	0.7870	
Cond/Sex/Age	6	0.85	0.5348	
Error	57			
Laterality	1	2.75	0.1135	
Laterality/Sex	1	0.00	0.9614	
Laterality/Age	2	0.34	0.7140	
Lat/Sex/Age	2	0.53	0.5955	
Error	19			
Condition/Laterality	3	0.42	0.7397	
Cond/Lat/Sex	3	2.90	0.0427	*
Cond/Lat/Age	6	0.79	0.5828	
Cond/Lat/Sex/Age	6	1.05	0.4051	
Error	57			
Position	2	6.61	0.0035	*
Position/Sex	2	2.61	0.0864	
Position/Age	4	1.74	0.1614	
Pos/Sex/Age	4	1.43	0.2439	
Error	38			
Condition/Position	6	3.45	0.0036	*
Cond/Pos/Sex	6	1.71	0.1250	
Cond/Pos/Age	12	1.64	0.0890	
Cond/Pos/Sex/Age	12	1.21	0.2832	
Error	114			
Laterality/Position	2	0.14	0.8724	
Lat/Pos/Sex	2	0.85	0.4339	
Lat/Pos/Age	4	1.03	0.4051	
Lat/Pos/Sex/Age	4	0.88	0.4851	
Error	38			
Condition/Lat/Pos	6	0.39	0.8862	
Cond/Lat/Pos/Sex	6	0.13	0.9915	
Cond/Lat/Pos/Age	12	1.12	0.3524	
Cond/Lat/Pos/Sex/Age	12	1.41	0.1722	
Error	114			

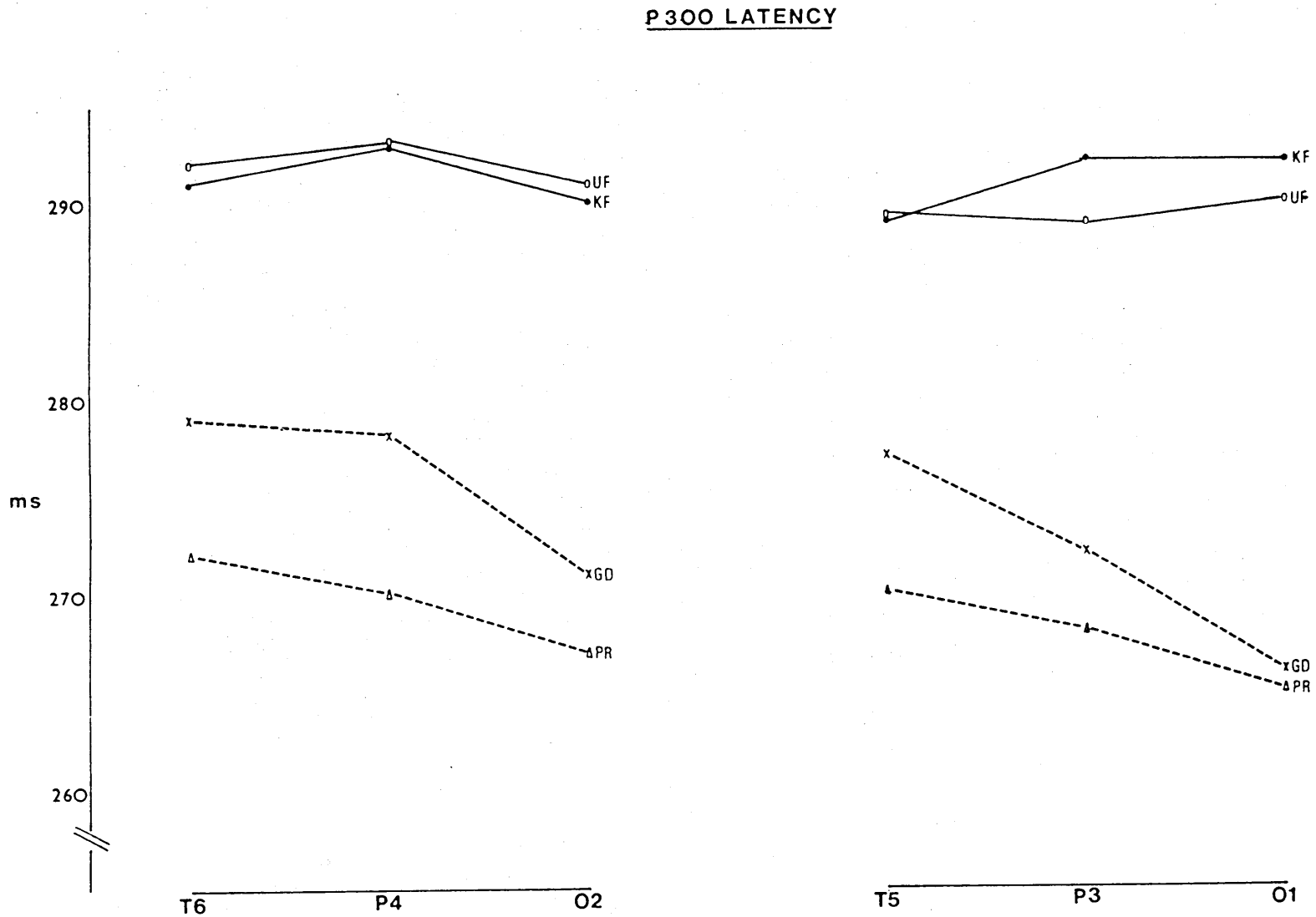


Fig 4:16. Latency (ms) of P300 plotted at the six electrode positions for the four stimulus conditions.

TABLE 4:17 P300 LATENCY Effect of Condition

	Temporal	Parietal	Occipital
KNOWN FACES	289.9	292.2	290.9
UNKNOWN FACES	290.7	291.1	290.5
GEOMETRIC DESIGNS	278.3	274.9	268.8
PATTERN REVERSAL	270.9	268.8	266.3

The latency of P300 shown according to the three recording positions (irrespective of hemisphere) under the four stimulus con-itions.

there was no significant interaction between condition and laterality, F (3,84) = 0.4, p= 0.7.

The position of electrodes proved significant, F (2,56) = 5.72, p< .01, with P300 occurring earlier in occipital regions (compared to temporal or parietal areas) with geometric designs and pattern reversal (condition x position effect F (6,168) = 3.74, p< .01). This finding can be seen clearly in Fig 4:16. There were no other significant interactions.

Effects of sex:

There were equal numbers of males and females (i.e. 15 of each). With P100 amplitude there was a general effect of sex, F (1,24) = 6.04, p<.05; the females showing generally larger responses than the males, in the order of 2.3 uV. The P100 amplitude position effect (maximal responses occipitally) interacted with sex, F (2,48) = 5.58, p< .01 with females showing larger responses in this area compared to males. There was also a condition x position x sex interaction, F (6,144) = 3.45, p< .01, due to the females showing the above effect more markedly with geometric designs and pattern reversal, (see Fig 4:18). P100 latency showed a general sex effect F (2,24) = 6.41, p< .05 and this result also occurred with P300 latency, F (1,19) = 6.55, p< .05. Females showed both earlier P100 latencies (7-8ms earlier) and P300 latencies (24 ms earlier). There were no other interactions.

Effects of Age:

For age, the subjects were divided into three groups, less than 27 (n=9), 27 to 33 (n=11) and older than 33 years (n=10). Age had no effect on the latencies of either P100 or P300. However, with P100 amplitude there was a condition x position x age effect, F (12,144) = 2.15, p< .05

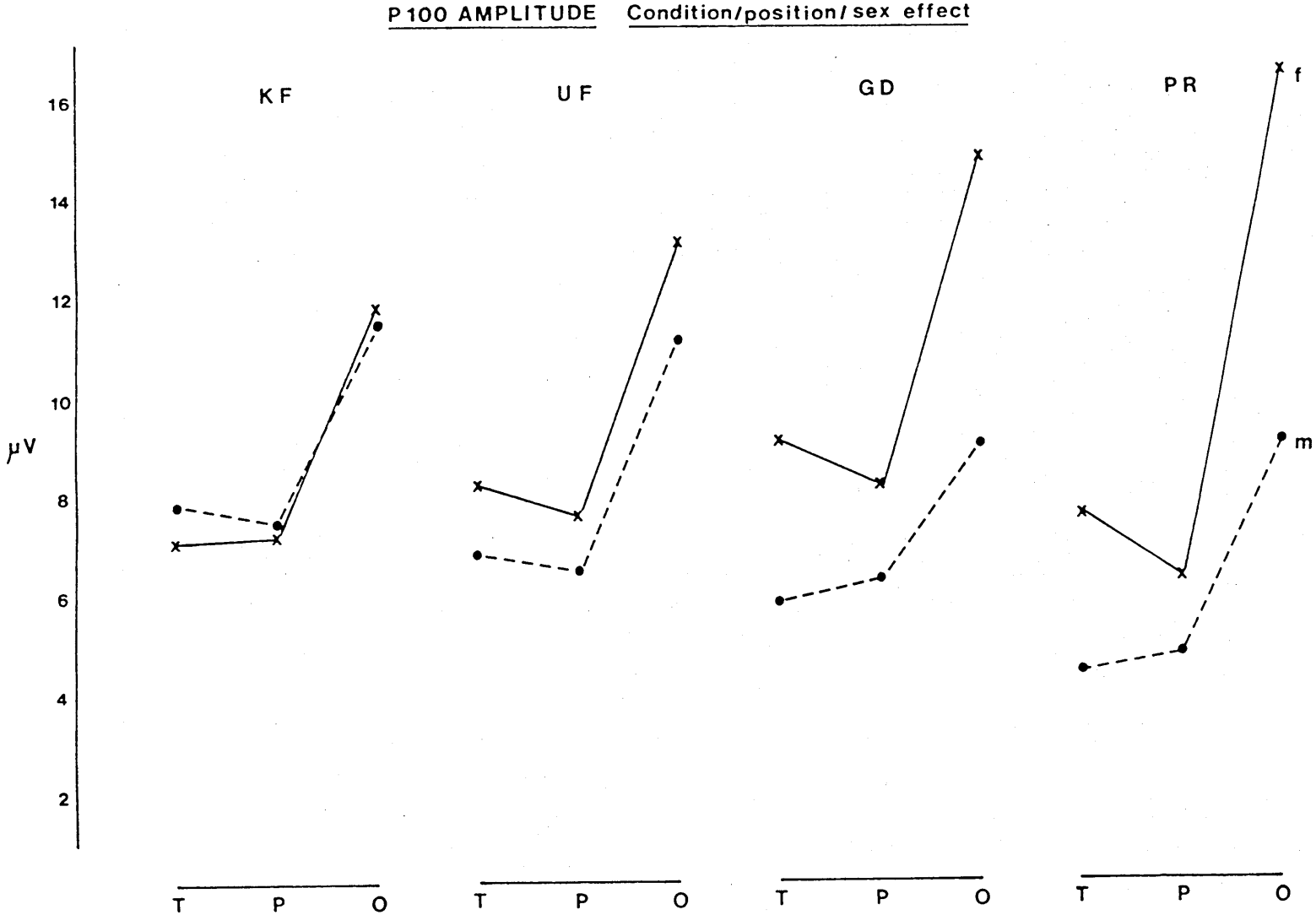


Fig 4:18. Amplitude (uV) of P100 shown for females (solid line) and males (dotted line) at the three recording positions (irrespective of hemisphere) under the four conditions.

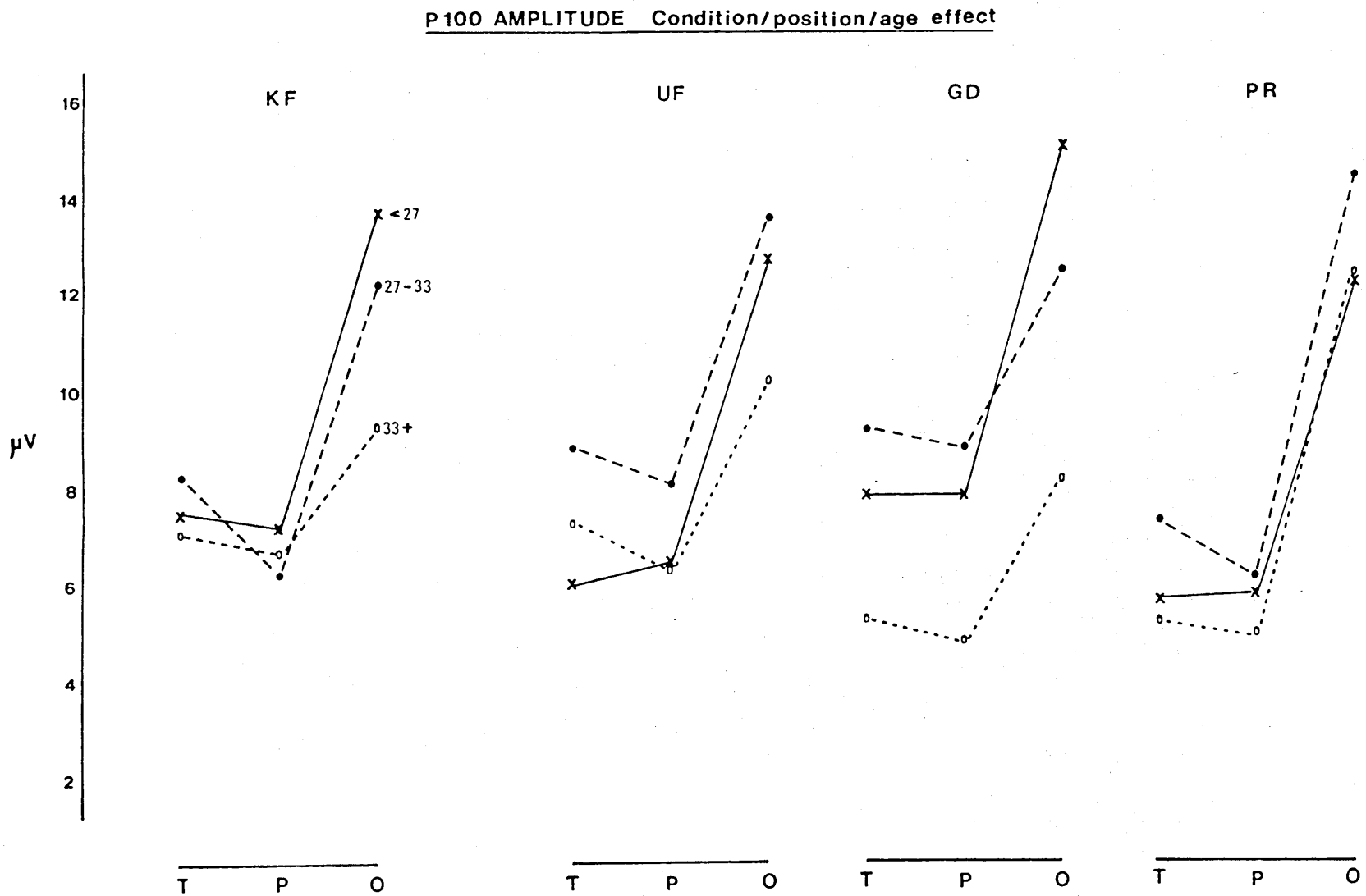


Fig 4:19. Amplitude (uV) of P100 shown for the three different age groups (i.e. less than 27 yrs, 27-33 yrs and >33yrs) at the three recording positions under the four stimulus conditions.

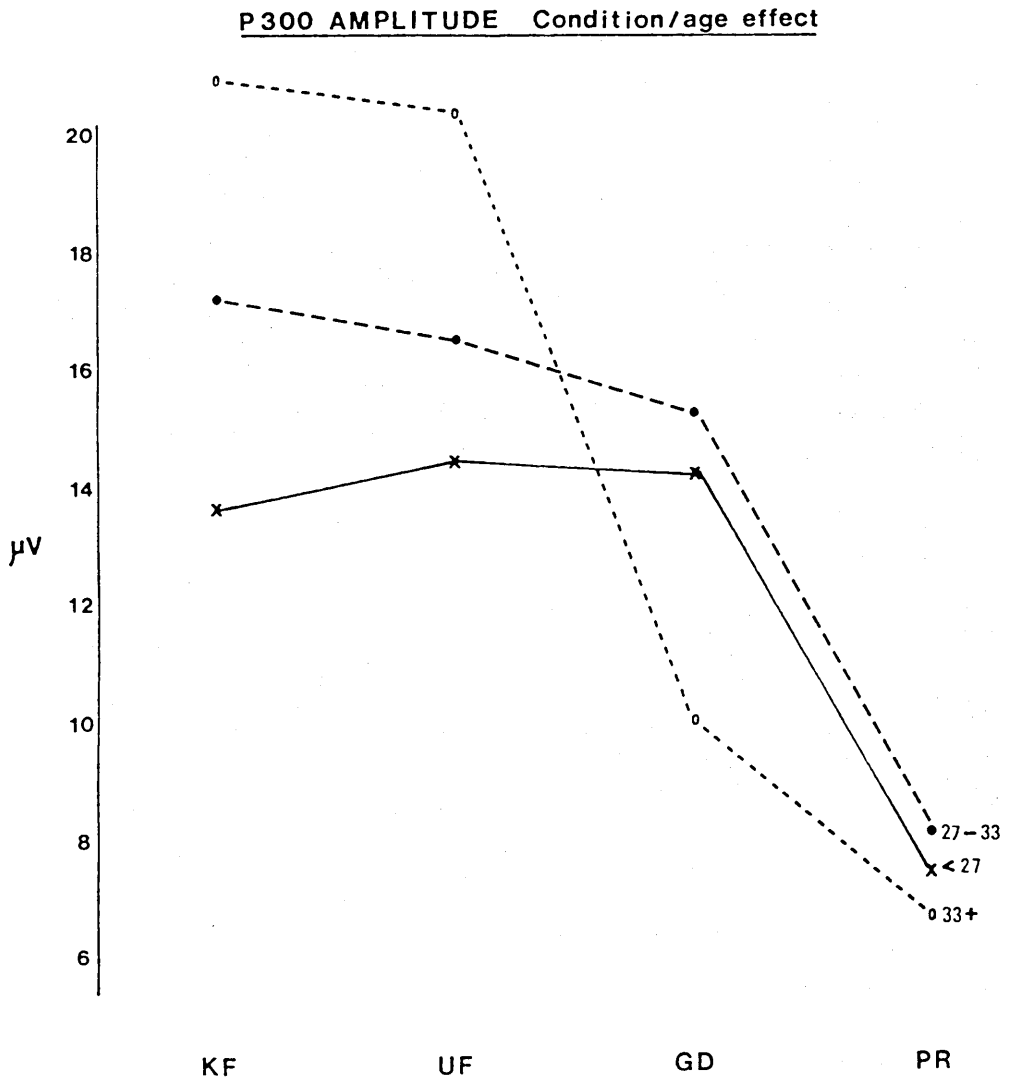


Fig 4:20 Overall mean amplitude (uV) of P300 for the 3 age groups under the 4 conditions.

which seems to be due to the older age group (33+ years) showing smaller responses in occipital regions with both face conditions and geometric designs, but not with pattern reversal, see Fig 4:19.

There was an age x condition effect with P300 amplitude, $F(6,57) = 6.19$, $p < .0001$. Fig 4:20 shows the mean amplitudes for the four conditions according to age. Those subjects over 33 years gave the largest responses to both face conditions, yet the smallest with geometric designs and pattern reversal.

Discussion of results.

These results replicate, in a much larger series of subjects, those already obtained by the small, preliminary study. It is evident that P100 and P300 can be evoked by viewing slides of faces when the only task is to watch the stimuli.

According to the type of stimuli presented, the amplitude and latency of P100 closely resemble the values reported in previous studies. With pattern reversal, the mean occipital latency and amplitude of 91-92 msec and 12-13 uV respectively are very similar to 90.5 msec and 9.2 uV given by Asselman et al. (1975) and to the means of 99 msec, 12.0 uV obtained during 1982 in the Department of Clinical Neurology from twenty normal controls (10 males; group mean age 33 yrs, range 19 - 60 yrs) using the same equipment. The P100 occipital latency recorded in response to the "flash presentation" of face stimuli (115-118 msec) is also similar to values in the literature, for example Ciganek (1969), 110 msec and Richey et al. (1971), 118 msec. It was not unexpected that P100 would occur with a longer latency in response to slides involving a flash presentation (compared to pattern reversal) and this finding corresponds to the different P100 latency values found in a comparison between flash

and pattern reversal by Hughes et al. (1982), i.e. P100 to flash occurred later. It is interesting to note that P100 occurred so much earlier with geometric designs (90-91 msec occipitally) than with face slides although both had the same method of "flash" presentation, and this is difficult to explain.

P300 to pattern reversal (265-270msec) also occurred at a similar time to the late positivity shown in response to this stimulus in the illustrations of Zeese et al. (1977) and Shahrokhi et al. (1978). To slides of faces it appeared slightly later (290 msec), in keeping with the P300 latency of 320 msec described by Lifshitz (1966) in response to scenic, nude and medical slides but considerably earlier than the P300 of 366 msec to coloured scenes reported by Shulman-Galambos and Galambos (1978) and to the positivity between 350-500 msec described by Neville et al (1982), who presented coloured slides of people, places and paintings.

As predicted, the results also show that P300 occurs, in response to faces, with a right hemisphere amplitude superiority significantly greater than that found with pattern reversal and geometric designs. The right hemisphere therefore seems to be more involved when processing faces than during evaluation of other visual stimuli and the asymmetry appears to be associated with "facial factors" rather than complexity. The right hemisphere amplitude superiority for faces was general and did not show any difference between electrode sites. Consequently, there is no evidence of a lateralised, discretely localised facial processing area.

The dissimilar topographies of P100 and P300 suggest that these two components may have different cortical generators. With all four conditions, P100 was clearly maximal in occipital regions. This finding corresponds to the reported area of maximum amplitude of P100 to flash

(Kooi et al., 1965) and pattern reversal (Halliday, McDonald and Mushin, 1973). In contrast, P300 appeared larger in both occipital and temporal areas; this was most marked with face stimuli. The more widespread distribution of this component suggests it has an alternative site of production to that of P100, possibly within the association areas. This finding is in keeping with the localisation of the late V.E.P. waveform (100-300 msec) found with simultaneous scalp and cortical recordings by Heath and Galbraith (1966), who suggested that the later components recorded from the occipital scalp may originate primarily in the temporal cortex.

It should be noted that P100 also showed a right greater than left amplitude asymmetry, but this appeared equally with all conditions. There was no additional P100 right sided superiority to faces as occurs with P300; these two components are therefore differentially affected by "face stimuli". If it is accepted that P100 reflects the physical properties of the stimuli, then this result supports the theory that P300 is in fact more involved with the cognitive, meaningful content of the slides.

The results did not confirm the findings of Neville et al (1982) who reported P300 to be larger for slides that were recognised as opposed to unrecognised. In the present study, no significant differences were found between slides of well known faces and those completely unknown to the subjects. However, the slides used by Neville et al. were coloured and were not limited to faces; they depicted people, places and paintings and are therefore not strictly comparable to the stimuli used in this study.

Faces, geometric designs and the pattern reversal slide were not matched for luminance; shapes and pattern reversal tended to be slightly

brighter than the slides of faces. Whilst a difference in luminance might contribute to variations in evoked potential amplitude, it is difficult to see how it could do so asymmetrically. Courchesne et al. (1978) found no dissimilarity between "P3" (300-600 msec) amplitudes of bright and dim slides bearing letters. However, their recordings were made from midline electrodes (Fz, Cz and Pz) so symmetry was not assessable.

The analysis for sex revealed some interesting findings. Females showed generally larger P100 responses than males, in the order of 2 uV, and this was most obvious in occipital regions. However, there was no difference in P300 amplitude between the sexes. The latencies of both P100 and P300 were earlier in females than males, by 7-8 ms and 24 ms respectively. Comparison of these results with previous studies proves difficult for very few earlier reports have investigated sex differences and those that have, have been specific to pattern reversal. The findings are in keeping with Kjaer (1985) who reports a larger amplitude and shorter E.P. latency in females. Yet Gastone, Celesia and Daly (1977), in a series of 40 females and 34 males, report that the amplitude of the V.E.P. did not vary with sex. Dustman et al. (1977), comparing 80 female and 80 male subjects, found that during childhood the male E.P.s were larger than those of females but the reverse was true during adolescence and adulthood. Females' potentials were then consistently larger although the differences were not specific to any electrode placement or component.

One possible explanation for the present differences found between the sexes is that males have an increased skull thickness which would attenuate the responses producing lower voltage potentials. However, if true, all components should be equally affected and while P100 was larger in females than males, P300 was not. Similarly, on the assumption that

skull growth is linear throughout development in both sexes, it is hard to explain the higher amplitude responses found in boys compared to girls during childhood yet the converse in later life (Dustman et al, 1977). While a slight variation in skull thickness may account for minute latency differences it is also unlikely to produce, in males, a P300 delay of 24 ms. Hormonal changes may play a part but otherwise the results remain unexplained.

Age had no effect on the latencies of either P100 or P300 and there was no general effect of age on amplitude. However, with P100, older subjects tended to show smaller responses with both face conditions and geometric designs but not with pattern reversal. Conversely, P300 was larger with the two face conditions (but not with the control stimuli) in the older subjects compared to the young. Again, previous literature is limited to the effects of age in response to pattern reversal and considerable controversy exists. With regard to age and the amplitude of P100, Celesia and Daly (1977) report no change; Perry and Childers (1969), Dustman et al (1977) and Kjaer (1985) state that there is an amplitude reduction with advancing age while Kooi and Bagchi (1964) describe an amplitude increase with age. The only mention of the relationship between P300 and age is by Dustman et al. (1977) who report a reduction of this component (with pattern reversal) from a mean of 7 uV at 13-20 years to 4 uV between 60-70 years. There was no latency change with age in the present study but the general consensus seems to be slightly prolonged components in the older subject by 7-14 ms for P100 (Asselman et al., 1975; Kjaer, 1985) and 20-30 ms for P300 (Dustman et al., 1977).

To summarise the main findings: Experiment 1 shows, that in respect

to P300, the right hemisphere is more involved in the processing of faces (in right handed individuals) compared to other complex visual stimuli with the right occipitotemporal region showing maximal responses. No difference was found between known and unknown slides of faces.

CHAPTER 5

EXPERIMENT 2

The evoked response to face and control stimuli in left handed subjects

Whilst the association between the left hemisphere and speech (and conversely the right hemisphere with non-linguistic functions) seems definite for dextrals, the picture is much less clear for sinistrals. For example, numerous studies of left handed aphasics have tended to show a much lower proportion of left hemisphere lesions and a higher proportion of right hemisphere lesions when compared to right handed aphasic groups. There is also evidence to show that often (but not always) aphasia tends to be less severe in left handed cases, (Chesner, 1936). Such facts have been thought by some to reflect more right hemisphere or bilateral representation of speech in left handers (Subirana, 1958, Zangwill 1960) and support for such a contention comes from the examination of left handers using the Wada technique, (Wada and Rasmussen, 1960). This is a method for unequivocally determining which cerebral hemisphere plays the major role in speech function. Following an injection of a rapidly acting anaesthetic agent into the internal carotid artery (which supplies one side of the brain) a temporary cessation of function occurs producing hemiplegia, hemianaethesia and hemianopia. If the hemisphere injected is dominant for language, dysphasia also occurs. The effects clear within about five minutes though subtle changes in language function may be elicited on careful examination for as long as half an hour after the injection. Both hemispheres can be investigated

since separate injections can be made on either side on two different occasions. [It should be mentioned at this point that a further complication arises because pure left handedness is rare and mixed handedness relatively common, (Annett, 1967),].

Branch et al (1964), using the intracarotid sodium amytal test on subjects under consideration for brain surgery, found a marked difference between the relationship of handedness to speech lateralisation in right and non-right handed patients, as shown in the following table.

		Speech representation		
Handedness	No of cases	Left	Bilateral	Right
Right	48	90%	0%	10%
Ambidextrous	20	60%	30%	10%
Left	51	43%	8%	49%

The right handed subjects are nearly all left hemisphere dominant for speech (90%). They show an absence of bilateral representation (0%) and only a small percentage of right sided representation (10%). The ambidextrous group are also mostly left hemisphere dominant for speech (60%), but they have a much higher percentage of bilateral representation (30%) and a small amount of right hemisphere dominance (10%). The left handed group however show a fairly equal distribution between the right and left hemispheres (43% vs 49%) and only a small amount of bilateral representation (8%). The right hemisphere speech dominance in this group (49%) is much higher compared to the right handed or ambidextrous subjects.

A closer examination by Milner (1974) shows a further difference when the left handed group of patients are divided into those with and without clinical evidence of early left hemisphere damage (within the first five years of life).

		Speech Representation		
Handedness	No of cases	Left	Bilateral	Right
Right	95	92%	1%	7%
Left or ambidextrous without early left hemisphere damage	74	69%	13%	18%
Left or ambidextrous with early left hemisphere damage	43	30%	16%	54%

It becomes clear that the "normal" left handers have a much higher proportion of left sided speech representation (69%) when compared to those with early left hemisphere damage, (30%). The difference between these two non-right handed groups seems to imply, in some cases at least, that right hemisphere speech representation is a reflection of early left hemisphere damage. However, the "normal" left handers still show less left sided and more right sided speech representation than right handers. Similar findings have been reported by Russell and Espir (1961) in their study of traumatic aphasia and its relationship to handedness in previously healthy men who sustained missile wounds to the brain.

A more recent study by Strauss and Wada (1983), using the Wada technique as part of the diagnostic procedure in epileptic patients, shows similar findings. The prevalence of right hemisphere speech dominance is significantly higher among individuals reporting left (as opposed to right) sided motor preference, as shown in the following table.

		Speech dominant hemisphere	
Handedness	No of cases	Left	Right
Right	62	94%	6%
Left	11	45%	55%

The authors observe that "the proportion of unilateral, left hemisphere representation of speech in the right handed and right footed group (more than 90%) is considerably higher than that observed in the left handed and left footed, even when the left handed and left footed with early brain damage are excluded." Thus the likelihood of a "normal" sinistral having left hemisphere speech representation (and consequently non-verbal functions in the right hemisphere) is markedly reduced compared to a right hander.

The second experiment in the present investigation, involving the same procedure as the first, was therefore carried out on a group of left handed normal subjects. Because, in theory, these controls should have a higher proportion of right hemisphere speech representation, (and consequently non-verbal functions, i.e. facial recognition, in the left hemisphere) the right greater than left P300 amplitude asymmetry, previously observed in right handers, should not be apparent. To take an extreme example: if the entire left handed group were to have right hemisphere speech representation, then the P300 emphasis to facial stimuli ought to appear with a clear reversed asymmetry (i.e. left greater than right). However, to obtain such a homologous sample of subjects is obviously highly unlikely. So, taking into consideration that subjects might have left, right or bilateral speech representation and hence be either right or left hemisphere dominant for facial recognition (though definitely having a higher proportion of left sided non-verbal functions than dextrals), it was expected that the left handed group, in response to face stimuli, would show no significant P300 amplitude asymmetry or alternatively a weak left greater than right P300 amplitude emphasis.

Brief procedure

Twenty two left handed subjects, 15 females and 7 males were studied. Their ages ranged from 14 to 62 years, mean age 32.9 years. Each subject was required to fill in a handedness questionnaire, a modification of the Oldfield Inventory, prior to testing. (This was omitted in three subjects). From Table 5:1 it is evident that most subjects were strongly left handed, 74% (14/19) being left sided for all of the 7 inventory items. Only 26% of subjects (5/19) showed any right sided preference, and those who did always wrote with the left hand and undertook more activities with the left, than with the right.

No subject gave any history of a change in lateral preference except subject X.G., who suffered a fractured skull at age 5 years. She was unsure if this injury preceded her left handedness. The overall group therefore showed no evidence of contamination by early neurological insult. The majority, 59% (13/22), gave a positive family history of left handedness, 41% (9/22) did not. In all subjects visual acuity was 6/9 or better in each eye, except M.L., whose left eye scored 6/18. Fourteen controls were right eye dominant, five were left eye dominant and three were not tested.

Each subject viewed the four types of stimuli (known and unknown faces, geometric designs and pattern reversal) during a single session. The presentation sequence of the conditions was randomised to overcome any order effect. Forty-two sweeps were averaged for known faces and sixty-four sweeps for the other three conditions. Pattern reversal alternated once every 1.5 seconds. As with Experiment 1, the recordings were made from electrodes placed over the right and left posterior temporal, parietal and occipital regions, with Fz acting as the reference.

LEFT HANDERS

TABLE 5:1

Subject n=22	Handedness Left	Handedness Right	Eye dominance	Change	Family History
AM	7	0	L	No	No
SM	*	*	R	"	"
EC	7	0	L	"	Yes
NB	7	0	L	"	No
RW	7	0	L	"	Yes
XG	*	*	L	poss	No
PS	7	0	L	No	Yes
NA	4	3	R	"	No
GA	*	*	L	"	Yes
SN	7	0	L	"	No
ML	7	0	L	"	Yes
JB	5	2	L	"	Yes
HW	4	3	R	"	Yes
BH	7	0	R	"	Yes
LN	7	0	*	"	No
MN	7	0	*	"	No
BF	7	0	L	"	Yes
RQ	7	0	*	"	Yes
DL	6	1	L	"	Yes
LH	5	2	R	"	No
DT	7	0	L	"	Yes
FA	7	0	L	"	Yes

Values under handedness indicate the number of activities undertaken with the left or the right hand, scored from a modified version of the Oldfield Inventory. Total number of activities = 7.

* Data unavailable

Results

Evoked potentials were consistently recorded from each left handed subject at all electrode sites for the four conditions and the typical response replicated the waveform previously shown by the right handed controls. Tables 5:2 and 5:3 give the mean latencies and amplitudes for P100 and P300 respectively, at each electrode site for the four types of stimuli.

The data from Experiment 2 conform to the same factorial analysis of variance (ANOVA) design used in the last experiment. An ANOVA was performed separately on each of the four dependent variables, namely P100 amplitude, P100 latency, P300 amplitude and P300 latency.

ANOVA: P100 amplitude

Table 5:4 and Fig 5:5 present the ANOVA results for P100 amplitude, $p < 0.05$ again being regarded as significant in respect to the table of probabilities. There is a significant effect of condition, $F(3,54) = 8.30$, $p < 0.001$, due to P100 being of larger amplitude with both known and unknown faces than with geometric designs and pattern reversal. The mean P100 amplitude for each condition, irrespective of laterality and electrode position, was as follows: known faces 10.3 uV, unknown faces 10.5 uV, geometric designs 8.5 uV and pattern reversal 7.5 uV. P100, in response to slides of faces, was therefore approximately 2-3 uV larger than with geometric designs and pattern reversal. The position of electrodes also proved significant, $F(2,36) = 44.09$, $p < 0.001$, with occipital regions showing maximum amplitude (12.8 uV) compared to temporal (7.8 uV) and parietal (6.9 uV) areas.

This effect of position interacts with condition, $F(6,108) = 7.54$, $p < 0.001$. Table 5:6 gives the mean P100 amplitude at the three electrode

P100 LATENCIES AND AMPLITUDES

TABLE 5:2

KNOWN FACES, UNKNOWN FACES, GEOMETRIC DESIGNS AND PATTERN REVERSAL: Left Handers

		T6	P4	O2	T5	P3	O1
known faces	lat	109.7 (18.9)	107.7 (19.2)	109.3 (18.9)	108.2 (19.3)	107.1 (18.5)	109.3 (18.9)
	amp	9.73 (4.8)	8.53 (3.7)	14.19 (7.3)	8.51 (4.4)	7.0 (3.1)	13.7 (6.9)
unknown faces	lat	110.2 (19.9)	108.5 (19.9)	110.0 (19.0)	107.7 (17.7)	105.0 (18.4)	109.5 (18.6)
	amp	9.53 (4.7)	8.62 (4.3)	14.75 (7.9)	8.57 (3.9)	7.56 (3.8)	14.29 (6.9)
geometric designs	lat	95.2 (16.8)	94.4 (15.5)	94.1 (16.6)	93.4 (15.3)	94.0 (14.9)	92.9 (14.6)
	amp	7.92 (3.4)	7.89 (3.4)	10.37 (4.6)	7.4 (3.0)	6.62 (3.1)	10.98 (4.6)
pattern reversal	lat	95.4 (13.0)	92.8 (10.9)	93.4 (10.4)	95.5 (13.5)	93.2 (13.2)	93.1 (12.7)
	amp	5.55 (2.8)	5.04 (2.5)	11.84 (5.3)	5.57 (2.3)	4.68 (2.2)	12.33 (5.1)

Brackets indicate respective standard deviations.

P300 LATENCIES AND AMPLITUDES

TABLE 5:3

KNOWN FACES, UNKNOWN FACES, GEOMETRIC DESIGNS AND PATTERN REVERSAL: Left handers

		T6	P4	O2	T5	P3	O1
known faces	lat	286.4 (37.5)	286.7 (37.1)	285.2 (39.0)	284.5 (38.2)	281.8 (36.5)	285.2 (35.7)
	amp	15.27 (7.8)	10.39 (5.0)	15.53 (8.1)	15.07 (8.5)	9.96 (5.3)	15.05 (7.6)
unknown faces	lat	277.6 (37.5)	277.9 (37.3)	272.6 (42.8)	276.8 (39.1)	276.9 (41.4)	276.4 (40.0)
	amp	16.25 (7.6)	10.35 (5.0)	15.19 (8.0)	15.28 (7.6)	9.54 (4.6)	13.72 (6.4)
geometric designs	lat	282.3 (58.6)	276.9 (46.1)	275.4 (52.6)	280.2 (57.0)	275.5 (47.7)	272.6 (48.6)
	amp	11.20 (4.3)	8.65 (3.8)	11.23 (5.8)	10.78 (4.4)	7.64 (4.0)	10.25 (5.6)
pattern reversal	lat	286.3 (51.2)	287.5 (50.7)	284.6 (48.7)	284.9 (47.6)	285.8 (48.1)	282.0 (49.3)
	amp	6.42 (3.3)	6.98 (4.2)	8.45 (4.4)	7.12 (4.6)	6.28 (4.1)	8.20 (4.5)

Brackets indicate respective standard deviations

P100 AMPLITUDE

TABLE 5:4

ANOVA Table of probabilities for Experiment 2

Known and unknown faces, geometric designs and pattern reversal (left handers)

Source	Degrees of Freedom	F	Probabilities	
Sex	1	2.45	0.1351	
Age	1	0.07	0.7958	
Sex/Age	1	0.13	0.7917	
Error	18			
Condition	3	8.30	0.0001	*
Condition/Sex	3	0.54	0.6574	
Condition/Age	3	2.94	0.0411	*
Cond/Sex/Age	3	0.87	0.4613	
Error	54			
Laterality	1	1.73	0.2046	
Laterality/Sex	1	0.32	0.5776	
Laterality/Age	1	0.94	0.3455	
Lat/Sex/Age	1	0.09	0.7737	
Error	18			
Condition/Laterality	3	2.23	0.0952	
Cond/Lat/Sex	3	0.06	0.9806	
Cond/Lat/Age	3	0.14	0.9342	
Cond/Lat/Sex/Age	3	0.86	0.4693	
Error	54			
Position	2	44.09	0.0000	*
Position/Sex	2	1.09	0.3462	
Position/Age	2	2.74	0.0781	
Position/Sex/Age	2	0.26	0.7717	
Error	36			
Condition/Position	6	7.54	0.0000	*
Cond/Pos/Sex	6	0.22	0.9699	
Cond/Pos/Age	6	3.53	0.0032	*
Cond/Pos/Sex/Age	6	0.34	0.9148	
Error	108			
Laterality/Position	2	3.29	0.0489	*
Lat/Pos/Sex	2	0.64	0.5338	
Lat/Pos/Age	2	0.09	0.9098	
Lat/Pos/Sex/Age	2	1.06	0.3583	
Error	36			
Condition/Lat/Pos	6	0.94	0.4704	
Cond/Lat/Pos/Sex	6	0.71	0.6389	
Cond/Lat/Pos/Age	6	0.28	0.9443	
Cond/Lat/Pos/Sex/Age	6	0.27	0.9484	
Error	108			

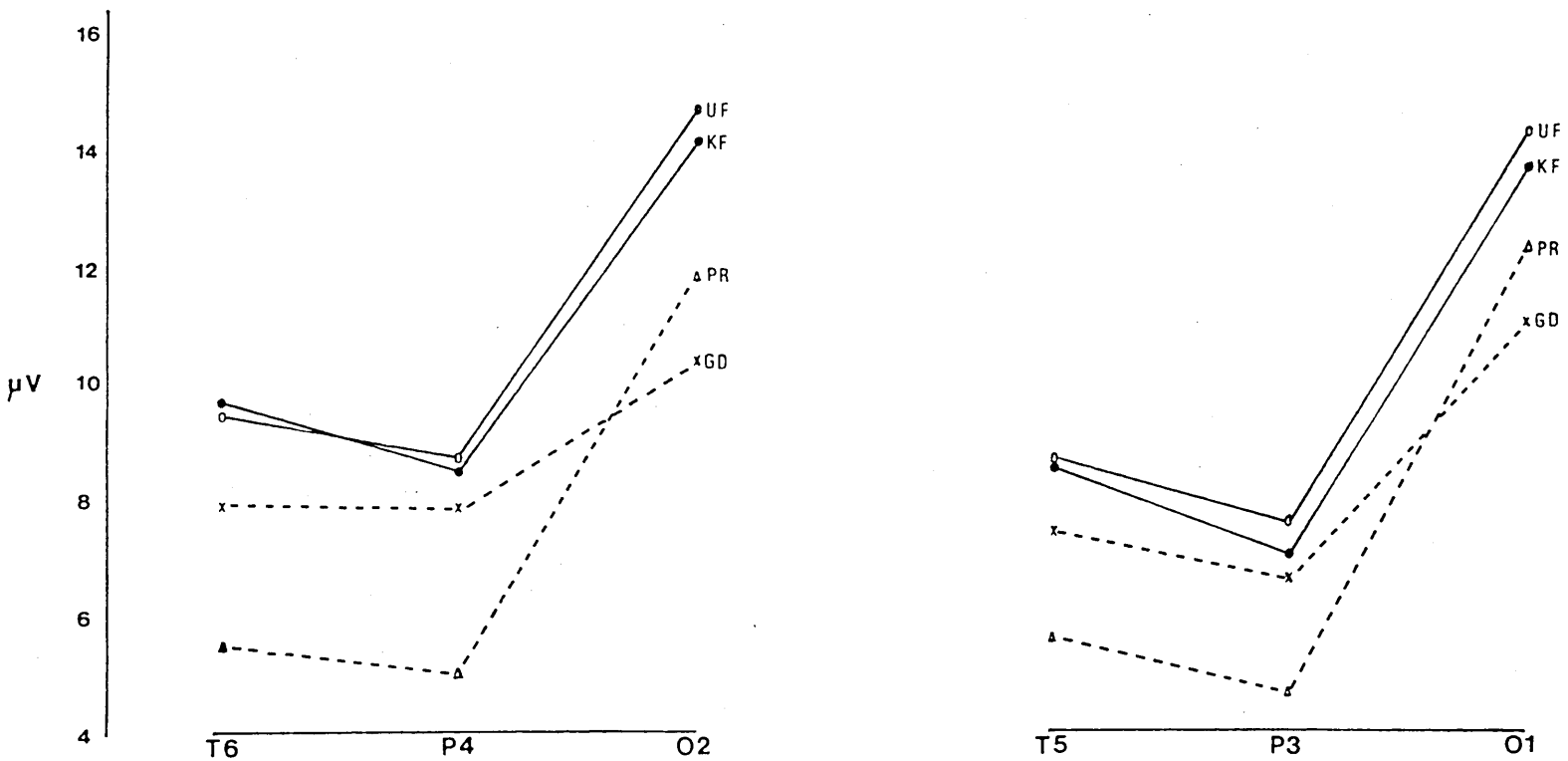


Fig 5:5 Amplitude (uV) of P100 at the six electrode positions under the four stimulus conditions.

P100 AMPLITUDE LEFT HANDERS

Effect of Condition v Position of electrodes

	Temporal	Parietal	Occipital
KNOWN FACES	9.12	7.77	13.94
UNKNOWN FACES	9.05	8.09	14.52
GEOMETRIC DESIGNS	7.66	7.26	10.67
PATTERN REVERSAL	5.56	4.86	12.09

Table 5:6 Amplitude (uV) of P100 at the three recording sites (irrespective of hemisphere) under the four stimulus conditions.

sites (irrespective of lateralisation) for each condition, and shows the interaction to be due to P100 occurring with smaller amplitudes in temporal and parietal areas (but not occipitally) with pattern reversal compared to the other conditions.

The laterality x position interaction is just significant, $F(2,36) = 3.29$, $p < 0.05$. Table 5:7 shows this effect to be caused by the right hemisphere showing slightly larger amplitude responses than the left side (in the order of 0.7 to 1.0 uV) in temporal and parietal areas, but not in occipital regions.

ANOVA: P100 Latency

The Anova results for P100 latency are shown in Table 5:8 and Fig 5:9. The only significant result is a general effect of condition, $F(3,54) = 13.47$, $p < 0.001$, due to P100 occurring earlier with the control conditions compared to slides of faces. The mean P100 latency (taken without regard to lateralisation or electrode position) for each condition was: both known and unknown faces 108.5 ms, geometric designs 94.0 ms and pattern reversal 93.9 ms. P100 therefore occurs approximately 14 ms earlier with geometric designs and pattern reversal when compared to both types of face stimuli.

ANOVA: P300 Amplitude

The Anova P300 results are shown in Table 5:10 and Fig 5:11. There is a general effect of condition, $F(3,54) = 6.80$, $p < 0.001$, with known and unknown face slides evoking higher amplitude responses than geometric designs, which in turn produce larger P300s than pattern reversal. The overall mean P300 amplitude for each condition was as follows: known faces 13.5 uV, unknown faces 13.4 uv, geometric designs 9.9 uV and pattern reversal 7.2 uV, so with face stimuli P300 is approximately 3.6

P100 AMPLITUDE LEFT HANDERS

Effects of Laterality v Position of electrodes

	Temporal	Parietal	Occipital
RIGHT HEMISPHERE	8.18uV	7.52	12.79
LEFT HEMISPHERE	7.51	6.46	12.83

Table 5:7 Overall mean amplitude of P100 for the right and left hemisphere at the three recording sites, irrespective of condition.

P100 LATENCY

TABLE 5:8

ANOVA Table of probabilities for Experiment 2

Known and unknown faces, geometric designs and pattern reversal (left handers)

Source	Degrees of Freedom	F	Probabilities	
Sex	1	0.04	0.8460	
Age	1	4.48	0.0486	*
Sex/Age	1	1.25	0.2784	
Error	18			
Condition	3	13.47	0.0000	*
Condition/Sex	3	0.40	0.7547	
Condition/Age	3	2.28	0.0897	
Cond/Sex/Age	3	0.45	0.7175	
Error	54			
Laterality	1	1.32	0.2662	
Laterality/Sex	1	0.03	0.8652	
Laterality/Age	1	1.09	0.3111	
Laterality/Sex/Age	1	0.00	0.9913	
Error	18			
Condition/Laterality	3	0.31	0.8173	
Cond/Lat/Sex	3	0.12	0.9464	
Cond/Lat/Age	3	2.54	0.0658	
Cond/Lat/Sex/Age	3	0.57	0.6363	
Error	54			
Position	2	2.71	0.0801	
Position/Sex	2	0.02	0.9797	
Position/Age	2	0.71	0.5007	
Position/Sex/Age	2	0.14	0.8686	
Error	36			
Condition/Position	6	1.33	0.2491	
Cond/Pos/Sex	6	0.46	0.8394	
Cond/Pos/Age	6	0.81	0.5678	
Cond/Pos/Sex/Age	6	0.61	0.7219	
Error	108			
Laterality/Position	2	0.29	0.7525	
Lat/Pos/Sex	2	0.29	0.7536	
Lat/Pos/Age	2	2.10	0.1366	
Lat/Pos/Sex/Age	2	0.36	0.6981	
Error	36			
Condition/Lat/Pos	6	0.59	0.7371	
Cond/Lat/Pos/Sex	6	0.16	0.9872	
Cond/Lat/Pos/Age	6	2.48	0.0275	*
Cond/Lat/Pos/Sex/Age	6	1.4	0.1716	
Error	108			

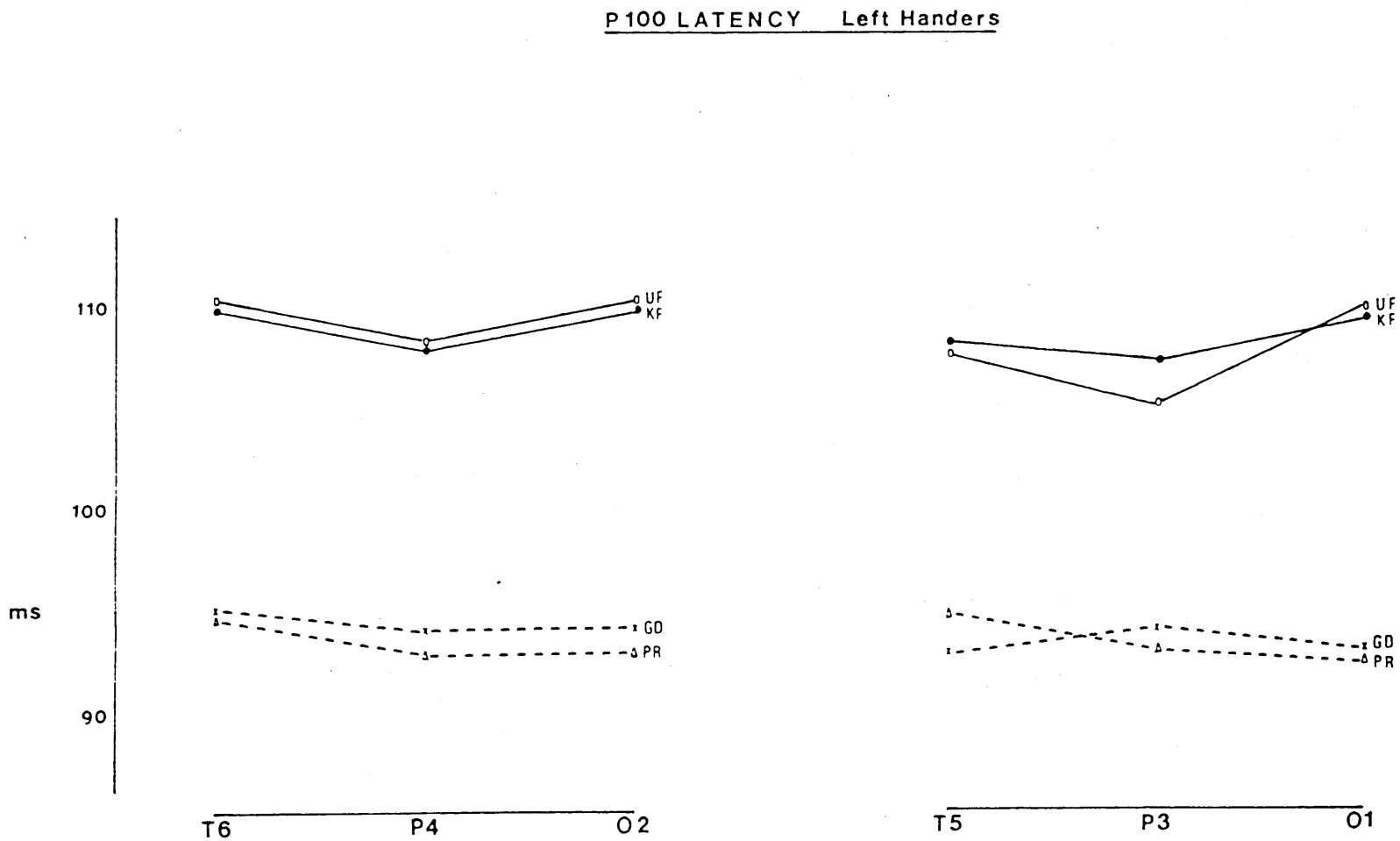


Fig 5:9 Latency (ms) of P100 at the six electrode positions under the four stimulus conditions.

P300 AMPLITUDE

TABLE 5:10

ANOVA Table of probabilities for Experiment 2

Known and unknown faces, geometric designs and pattern reversal (left handers)

Source	Degrees of Freedom	F	Probability	
Sex	1	0.00	0.9763	
Age	1	0.03	0.8547	
Sex/Age	1	1.55	0.2297	
Error	18			
Condition	3	6.80	0.0006	*
Condition/Sex	3	0.17	0.5477	
Condition/Age	3	1.84	0.1513	
Cond/Sex/Age	3	0.25	0.8600	
Error	54			
Laterality	1	1.51	0.2349	
Laterality/Sex	1	1.14	0.3002	
Laterality/Age	1	4.55	0.0470	*
Lat/Sex/Age	1	0.51	0.4858	
Error	18			
Condition/Laterality	3	0.97	0.4119	
Cond/Lat/Sex	3	1.05	0.3771	
Cond/Lat/Age	3	1.18	0.3243	
Cond/Lat/Sex/Age	3	0.84	0.4762	
Error	54			
Position	2	12.99	0.0001	*
Position/Sex	2	1.30	0.2850	
Position/Age	2	0.01	0.9878	
Pos/Sex/Age	2	2.56	0.0914	
Error	36			
Condition/Position	6	7.00	0.0000	*
Cond/Pos/Sex	6	0.48	0.8247	
Cond/Pos/Age	6	0.73	0.6234	
Cond/Pos/Sex/Age	6	0.46	0.8373	
Error	108			
Laterality/Position	2	0.50	0.6081	
Lat/Pos/Sex	2	0.73	0.4876	
Lat/Pos/Age	2	1.62	0.2128	
Lat/Pos/Sex/Age	2	1.63	0.2109	
Error	36			
Condition/Lat/Pos	6	0.71	0.6417	
Cond/Lat/Pos/Sex	6	0.41	0.8690	
Cond/Lat/Pos/Age	6	2.13	0.0558	
Cond/Lat/Pos/Sex/Age	6	1.69	0.1300	
Error	108			

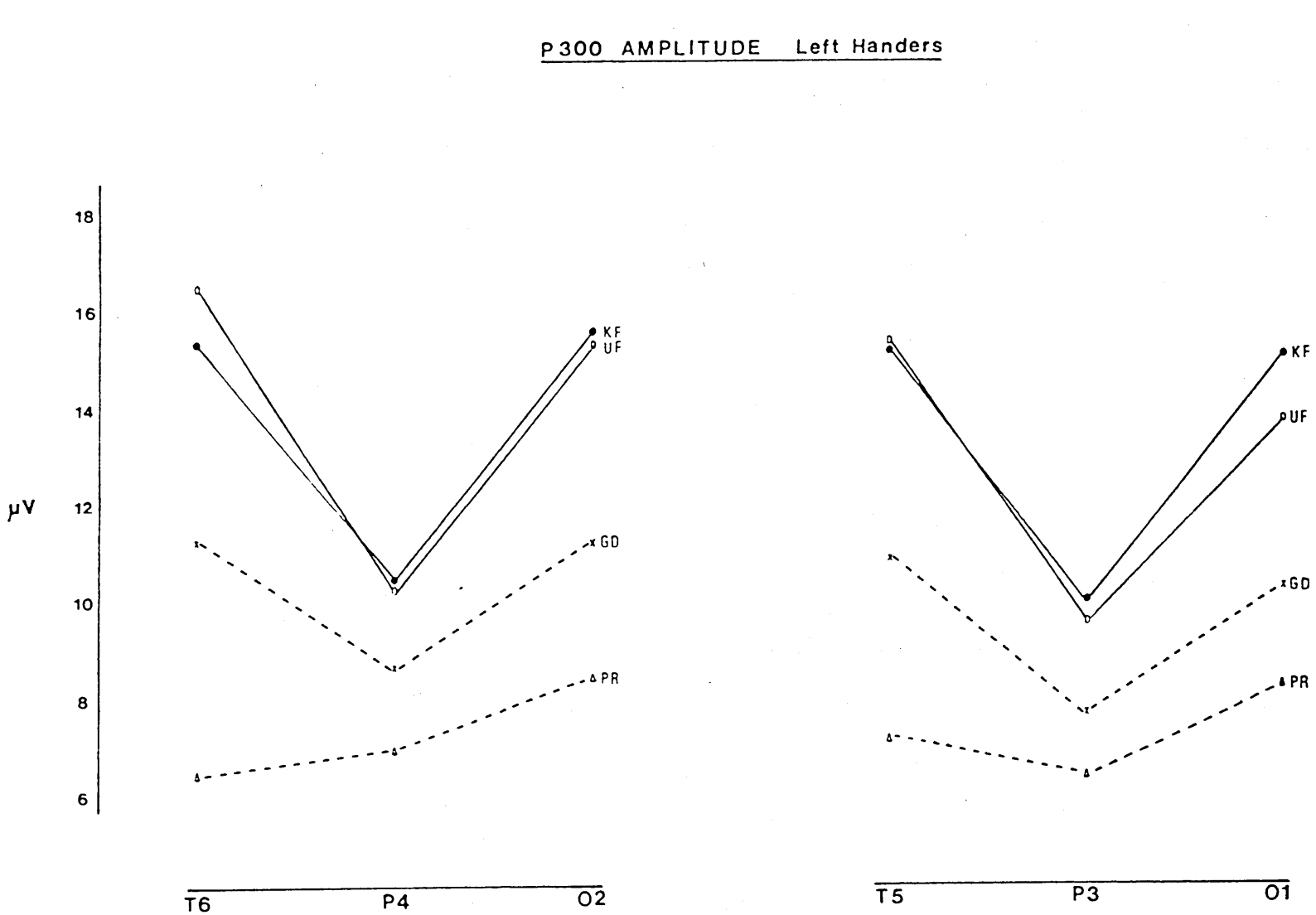


Fig 5:11 Amplitude (uV) at the six electrode positions under the four stimulus conditions.

uV and 6.3 uV larger than geometric designs and pattern reversal respectively.

There is also a general effect of position, $F(2,36) = 13.0$, $p<0.001$, which does not interact with laterality. The mean P300 amplitude for the three electrode sites (irrespective of hemisphere and condition) was: temporal 12.2 uV, parietal 8.7 uV and occipital 12.2 uV. This effect of position shows a significant interaction with condition, $F(6,108) = 7.0$, $p< 0.001$. Table 5:12 shows the mean P300 amplitude at each electrode site (irrespective of lateralisation) under the four conditions and indicates that the interaction is due to P300 appearing in the parietal region with face stimuli at a much smaller amplitude compared to the same area during the control conditions.

It should be noted that there is no significant laterality effect or laterality x condition interaction for P300 amplitude.

ANOVA: P300 Latency

Table 5:13 and Fig 5:14 show the ANOVA results for P300 latency. The effect of laterality is just significant, $F(1,18) = 6.06$, $p <0.05$, due to P300 occurring 1.4 ms later over the right hemisphere (mean 281.6 ms) compared to the left side (mean 280.2 ms). There is also a condition x laterality x position interaction which is just significant, $F(6,108) = 2.19$, $p< 0.05$. Table 5:15 gives the mean P300 latencies according to condition, electrode position and laterality and shows the calculated differences in latency between the two hemispheres. The significant interaction appears to be due to the fact that the difference between the right and left parietal regions, during the known face condition, is considerably greater (5.0 ms) than any of the other calculations.

P300 AMPLITUDE LEFT HANDERS

Effects of condition x position of electrodes

	Temporal	Parietal	Occipital
KNOWN FACES	15.17 uV	10.17	15.29
UNKNOWN FACES	15.90	9.94	14.45
GEOMETRIC DESIGNS	10.99	8.15	10.74
PATTERN REVERSAL	6.77	6.63	8.33

Table 5:12 Amplitude of P300 at the three recording sites (irrespective of hemisphere) under the four stimulus conditions.

P300 LATENCY

TABLE 5:13

ANOVA Table of probabilities for Experiment 2

Known and unknown faces, geometric designs and pattern reversal (left handers)

Source	Degrees of Freedom	F	Probability	
Sex	1	0.18	0.6725	
Age	1	0.16	0.6934	
Sex/Age	1	3.46	0.0793	
Error	18			
Condition	3	0.93	0.4340	
Condition/Sex	3	1.32	0.2764	
Condition/Age	3	0.56	0.6418	
Cond/Sex/Age	3	0.91	0.4434	
Error	54			
Laterality	1	6.06	0.0242	*
Laterality/Sex	1	3.20	0.0905	
Laterality/Age	1	4.60	0.0459	*
Lat/Sex/Age	1	4.46	0.0489	*
Error	18			
Condition/Laterality	3	0.73	0.5375	
Cond/Lat/Sex	3	0.12	0.9495	
Cond/Lat/Age	3	0.38	0.7650	
Cond/Lat/Sex/Age	3	1.41	0.2491	
Error	54			
Position	2	0.80	0.4586	
Position/Sex	2	0.64	0.5311	
Position/Age	2	0.39	0.6812	
Pos/Sex/Age	2	2.73	0.0788	
Error	36			
Condition/Position	6	0.48	0.8198	
Cond/Pos/Sex	6	1.70	0.1271	
Cond/Pos/Age	6	0.18	0.9808	
Cond/Pos/Sex/Age	6	1.06	0.3909	
Error	108			
Laterality/Position	2	1.02	0.3710	
Lat/Pos/Sex	2	1.59	0.2175	
Lat/Pos/Age	2	4.60	0.0167	*
Lat/Pos/Sex/Age	2	0.32	0.7273	
Error	36			
Condition/Lat/Pos	6	2.19	0.0496	*
Cond/Lat/Pos/Sex	6	1.01	0.4252	
Cond/Lat/Pos/Age	6	1.50	0.1865	
Cond/Lat/Pos/Sex/Age	6	2.94	0.0107	*
Error	108			

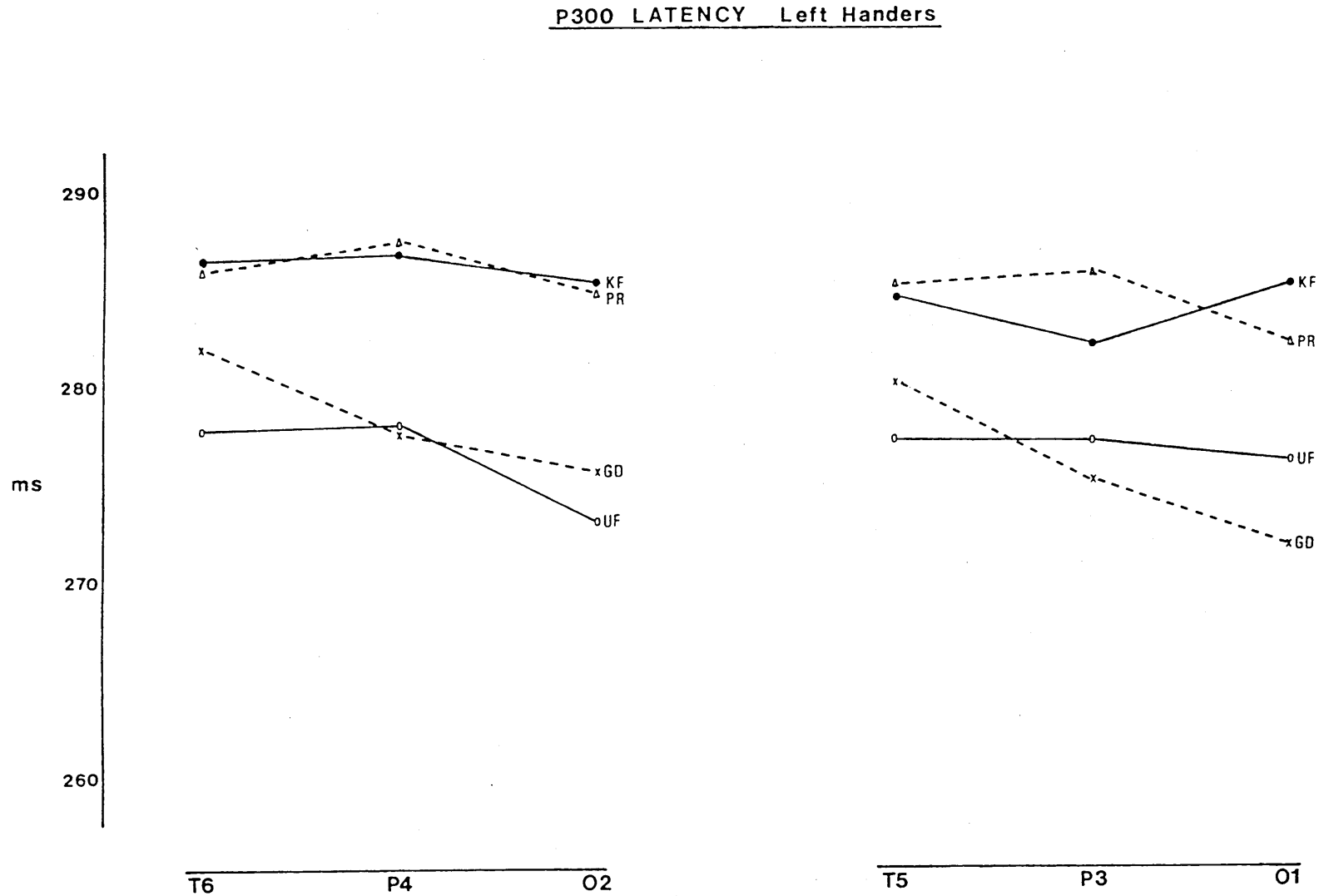


Fig 5:14 Latency (ms) of P300 at the six electrode positions under the four stimulus conditions.

P300 LATENCY LEFT HANDERS

Effects of condition x laterality x electrode position

		Temporal		Parietal		Occipital	
KNOWN FACES	Right	286.4	(1.9)	286.7	(5.0)	285.2	(0)
	Left	284.5		281.7		285.2	
UNKNOWN FACES	Right	277.6	(0.8)	277.9	(1.0)	272.6	(-3.8)
	Left	276.8		276.9		276.4	
GEOMETRIC DESIGNS	Right	282.3	(2.1)	276.9	(1.4)	275.4	(2.8)
	Left	280.2		275.5		272.6	
PATTERN REVERSAL	Right	286.3	(1.4)	287.5	(1.7)	284.6	(2.6)
	Left	284.9		285.8		282.0	

Table 5:15 The latency of P300 from the right and left hemispheres, at the three recording sites under the four stimulus conditions. Difference in latency between hemispheres shown in parenthesis.

Effects of Sex:

There were 15 female and 7 male subjects. The ANOVAs for P100 amplitude, P100 latency and P300 amplitude show no significant sex effects. With P300 latency there is a significant condition x laterality x position x sex x age interaction, $F(6,108) = 2.94$, $p < 0.05$.

Effects of Age:

For age, the subjects were divided into two groups, less than 26 years, n = 8 (4 females, 4 males) and over 26 years, n = 14 (11 females, 3 males).

Age & P100 Amplitude

With P100 amplitude there was no general effect of age, but there was a significant condition x age interaction, $F(3,54) = 2.94$, $p < 0.05$. These two factors also interacted with position: condition x position x age, $F(6,108) = 3.53$, $p < 0.01$. Table 5:16 shows the mean P100 amplitude values under each condition at the three electrode sites (irrespective of sex and laterality) for each age group. The differences in the P100 amplitudes between the two age groups have been calculated and are shown in parentheses. These values indicate that generally the amplitude of P100 is very similar between the two age groups at the same electrode site and under the same condition, differences when present being in the order of 1-2 uV. The significant interaction appears to be due to the much larger differences (4-5 uV) between the two age groups in occipital regions with both known and unknown face conditions. In both cases, in occipital areas, the younger age group shows higher amplitude responses than the older subjects.

Age & P100 Latency

The P100 latency ANOVA shows a general age effect which is just

AGE & P100 AMPLITUDE LEFT HANDERS

Effect of condition x position x age

		Temporal	Parietal	Occipital
KNOWN FACES	under 26	10.19	8.03	16.66 uV
		(2.18)	(0.89)	(5.4)
	over 26	8.01	7.14	11.26
UNKNOWN FACES	under 26	9.40	7.31	16.67
		(0.88)	(-1.24)	(4.33)
	over 26	8.52	8.55	12.43
GEOMETRIC DESIGNS	under 26	6.74	6.01	10.04
		(-0.83)	(-1.73)	(0.01)
	over 26	7.57	7.74	10.03
PATTERN REVERSAL	under 26	4.01	3.73	10.60
		(-2.31)	(-1.43)	(-1.25)
	over 26	6.32	5.16	11.85

Table 5:16 Amplitude of P100 at the three recording sites (irrespective of hemisphere) for the two age groups under the four stimulus conditions. Difference in amplitude between the two age groups shown in parenthesis.

significant, F (1,18)= 4.48, p< 0.05. This does not interact with sex and so the subjects have been divided into two groups (under and above 26 years) regardless of sex and the overall mean P100 latencies calculated for both groups. The means were 109.5 ms and 97.9 ms for the young and old groups respectively, the significant effect of age being due to P100 occurring 11 ms earlier in older subjects.

There is also a condition x laterality x position x age effect, F (6,108) = 2.48, p< 0.05.

Age & P300 Amplitude

For P300 amplitude, there was a significant effect between laterality and age, F (1,18)= 4.55, p< 0.05 but no other interactions. The overall mean amplitudes of P300 over the right and left hemispheres for the young and old age groups were as follows: under 26 years, right 11.2 uV, left 9.6 uV; over 26 years, right 10.6 uV, left 11.0 uV. The laterality x age effect seems to be due, not to the difference between the hemispheres of the older age group which was small (0.4 uV) but to the greater discrepancy (1.6 uV) in the younger age group. Subjects under 26 years showed significantly larger P300 amplitudes over the right hemisphere compared to the left side and this occurred equally with all four conditions, irrespective of sex and electrode position.

Age & P300 Latency

The ANOVA for P300 latency shows a significant laterality x age effect, F (1,18)= 4.60, p< 0.05, and these two factors interact with position, F (2,36)= 4.60, p<0.05. Table 5:17 gives the mean P300 latency at the three electrode positions over each hemisphere, for the two age groups. The differences in latency between each hemisphere have also been calculated and are shown in parentheses. Generally, these differences are

AGE & P300 LATENCY LEFT HANDERS

Effect of Laterality x Position x Age

	Temporal	Parietal	Occipital
Under 26 years	Right 281.0 (2.5) Left 278.5	Right 281.8 (8.2) Left 273.6	Right 278.2 ms (-2.1) Left 280.3
Over 26 years	Right 273.9 (1.1) Left 272.8	Right 272.7 (-1.5) Left 274.2	Right 271.2 (1.1) Left 270.1

Table 5:17 Latency of P300 over the right and left hemispheres at the three recording sites (irrespective of condition) for the two age groups. The difference in latency between the two hemispheres shown in parenthesis.

in the order of 1-2 ms, but from the table it can be seen that P300 occurs much earlier on the left side (a difference of approximately 8 ms) in the parietal region of the younger age group, giving rise to the significant laterality x position x age interaction.

Discussion of results.

In many respects the results from the left handed subjects replicate those of the right handed group described in Experiment 1. P100, according to the condition, appears with similar mean latencies and amplitudes, maximum voltage again occurring in occipital regions. The left handers show the same P100 latency discrepancy between conditions as the right handed group, i.e. this component occurs earlier with geometric designs and pattern reversal compared to known and unknown face stimuli. The difference however is less marked in the left handers, being approximately 14 msec compared to the 25 msec difference observed in the right handers.

The results for P300 amplitude and latency also resemble those of Experiment 1. This component again shows maximum amplitude in temporal and occipital areas and occurs with a higher amplitude during both face conditions compared to geometric designs and pattern reversal. Taking into consideration the marked variability in the latency of P300 (reflected in the large standard deviations) the times are not unlike those of the right handed group. However, the left handers show a fairly uniform P300 latency during all four conditions (272-287 ms). The previous latency difference observed in the right handed group, between the face conditions (289-293 ms) and the control stimuli (265-279 ms), is not apparent. The left handers do show an interesting general laterality

effect for P300 latency with this component occurring approximately 1.4 msec later in the right hemisphere (compared to the left side) during each condition and at all electrode sites.

There were no striking effects of sex on any of the component variables so although the previous right handed group did show significant findings related to sex they have not been replicated. This lack of reproducibility is in accordance with the conflicting results regarding sex effects in the literature (Gastone et al 1977; Dustman et al, 1977). Age again proved significant for P100. As with right handed subjects, the older left handed group showed smaller amplitudes for this component with face slides compared to younger controls. There was no difference in P300 amplitude between the age groups. While Experiment 1 reported no difference in the latency of either P100 or P300 with age, the left handers showed earlier P100 latencies with increasing age.

The most important finding of Experiment 2 is the lack of a significant laterality x condition effect for P300 amplitude in left handers, as predicted. In other words, there is no significant right hemisphere amplitude superiority in response to faces (as occurred with the right handed subjects), nor is there a reversed P300 amplitude asymmetry, i.e. left greater than right. Because the left handers comprised a group that can be assumed to have either right or left hemisphere non-verbal representation, this negative result supports the contention that the P300 amplitude asymmetry in response to face stimuli, previously reported for right handers, does indeed reflect organisation of cerebral function.

In order to investigate this finding more fully the left handers can be further analysed, for there is evidence to suggest that a distinction can be made between familial and non-familial left handers

according to which hemisphere is dominant for speech. Zurif and Bryden (1969), defining familial left handers as those with at least one left handed parent or sibling, found that such subjects showed inconsistent cerebral dominance according to tests based on dichotic listening and tachistoscopic visual preception. Non-familial left handers however showed the usual left hemisphere dominance for the processing of verbal items. Hecaen and Sauguet (1971) compared the effects of left and right hemisphere lesions on language functions among familial and non-familial left handers. Again, the familial group were equally divided in terms of which hemisphere was dominant for language, while the non-familial group was almost exclusively left hemisphere dominant. There is also evidence that recovery from aphasia is faster and more complete among familial than among non-familial left handers (Luria, 1969), suggesting that the former group show a greater degree of equipotentiality between hemispheres.

It was hypothesized therefore that the non-familial group would produce results similar to the right handers, i.e. a right greater than left P300 amplitude superiority to face stimuli, whereas the familial left handers would show no overall P300 asymmetry as a group, (some being R>L and some L>R). The strongly left handed subjects (only those who scored 7/7 on the handedness questionnaire) were divided into two groups, namely those with and those without a family history of sinistrality, n=9 and 5 respectively. Using an Analysis of Variance, their evoked potential data were then reanalysed according to these two new categorisations.

All four ANOVAs (again performed separately on P100 amplitude, P100 latency, P300 amplitude and P300 latency) showed no significant effect between latency, condition and familial vs non-familial subjects. Neither

the familial left handers or those with a negative family history therefore showed a P300 amplitude asymmetry to face stimuli; there was no difference between the two groups. While this result refutes the proposed hypothesis it can perhaps be explained by observing that the method used to categorise the two groups contains an inherent drawback. A subject's knowledge of his/her family history of left handedness may not be factual. For example, a subject may be ignorant concerning a parent born left handed but who was, due to social pressures, forced to write with the right hand. The non familial group may then be contaminated by subjects who actually should have been classified as familial and any real difference between the two categories is minimised.

To summarise the main findings of Experiment 2:

In most respects the results of the left handed subjects closely resemble those reported for the right handers. However, they show no significant P300 amplitude asymmetry to face stimuli even with further analysis following the classification of subjects into those with and those without a positive family history of left handedness.

CHAPTER 6

EXPERIMENT 3

The evoked response to inverted face stimuli in right handed subjects

The results of the first experiment in the present study showed clearly that in right handed normal controls upright faces are processed asymmetrically, with a significant right hemisphere amplitude superiority. The recognition of inverted faces, however, appears to be dissociable from that of upright faces according to the evidence provided by Yin (1970). As described earlier, Yin observed that patients with right posterior brain damage were impaired in the recognition of upright faces compared with normal controls and other unilateral patients, but their performance with inverted faces was not inferior to that of the controls and was significantly better than the left posterior lesion group. When the tests were repeated with pictures of houses, this interaction was not found. Recognition of inverted faces, therefore, may not be specifically carried out in the right hemisphere.

Unknown inverted faces

Yin's results have been extrapolated to the situation where normal subjects are presented with upright and inverted faces in each half field, the prediction being that upright faces would be better recognised when shown in the left visual field (right hemisphere) while inverted faces would be better recognised when projected to the right visual field (left hemisphere). Ellis and Shepherd (1975) tested this hypothesis in eight right handed controls, who were asked to decide whether a face exposed for 15 ms in one half field was the same as or different from a

comparison face presented full-field for 5 secs. There was no difference in accuracy between upright and inverted conditions and recognition performance was found to be more accurate for both types of faces when shown in the left visual field (LVF) regardless of orientation. This suggests that faces in any orientation are processed better by the right hemisphere, a finding at variance with the prediction based on Yin's (1970) results from brain damaged patients.

That Ellis and Shepherd (1975) found no overall advantage for the recognition of upright faces is also in striking disagreement with the results obtained using a variety of non-tachistoscopic paradigms; for example performance on upright faces has been shown to be better than that of inverted faces in tasks requiring recognition of familiar faces (Goldstein, 1975; Rock, 1974) as well as with subsequent recognition of unfamiliar faces (Hochberg and Galper 1967; Yarmey, 1971). Leehey, Carey, Diamond and Cahn (1978) suggest Ellis and Shepherd's absence of an inversion effect was due to the use of such a brief stimulus exposure time (15 ms) which could have precluded the stimuli from being processed as faces. Chi (1977) has reported that the threshold for recognition of a centrally presented photograph of a highly familiar face is approximately 42 ms. Using the same experimental procedure with 71 right handed controls (except for bilateral tachistoscopic presentation and a much longer exposure time of 120 ms) Leehey et al found that for both types of stimuli there was a left visual field advantage. However, while upright faces were recognised significantly better in the left half field ($p < 0.001$) than in the right half field (RVF), the left visual field advantage for inverted faces failed to reach significance. Upright faces were also more accurately recognised than inverted faces ($p < 0.01$), a

result which differs from Ellis and Shepherd's failure to find an effect of orientation. Leehey et al suggest that the discrepancies (i.e. the visual field result and the orientation effect) can be attributed to the difference in exposure duration between the two studies.

Leehey et al's result that upright faces show a left visual field advantage replicate those of Ellis and Shepherd's experiment using similarly orientated faces. However, the fact that inverted faces showed no such significant effect is relevant to the issue of a "speciality" for facial processing within the right hemisphere. If the LVF (right hemisphere) advantage merely reflects a superiority for processing any type of complex stimulus it should not be affected by inversion, since a face is equally complex as a visual stimulus whether upright or inverted. On the other hand, if the LVF advantage implies a superiority specific to processing upright faces, then inversion of the stimulus should reduce or eliminate any such effect. Leehey et al's results conform to the latter suggestion, providing evidence for a component of right hemisphere involvement which is special, in the sense that the LVF advantage operates with upright faces but not with inverted faces.

Known inverted faces

The studies of upright and inverted faces described up to now have used faces of people not known to the subjects. Encoding of unfamiliar faces may depend on rather different processes to those used in the recognition of familiar faces and it is therefore of interest to ascertain whether a different type of laterality effect is found when upright and inverted familiar, rather than unfamiliar, faces are used as stimuli. The studies in which laterality effects and the processing of upright familiar faces have been investigated have not, unfortunately,

produced consistent results. Marzi and Berlucchi (1977) found a RVF superiority for the naming of photographs of faces of famous people but in contrast, Leehey and Cahn (1979) report a LVF superiority for the processing of faces of people known personally to the subjects. There were a number of procedural differences between these two studies which could have contributed to the discrepant results, for example Marzi and Berlucchi used unilateral projection while Leehey and Cahn's subjects viewed bilaterally presented faces.

Young and Bion (1981) have incorporated into one study all these methodological variations in an attempt to explain the previous inconsistent results. Familiar faces were presented both upright and inverted in order to establish whether any obtained LVF superiority reflected a specific facial processing system or a more general perceptual ability within the right hemisphere. Forty-seven primary school children and twenty adults, all right handed, were required to name personally known faces (classmates or colleagues) presented tachistoscopically for 150 ms. Each subject performed the task under bilateral and unilateral presentation conditions with the stimulus faces in both upright and inverted orientations. The results showed that upright faces were more accurately named than inverted faces and that a LVF advantage arose only with the upright faces. Inverted faces, presented bilaterally and unilaterally, showed no significant difference between left and right half fields. These findings confirm and extend the observations of Leehey and Cahn (1979), for the LVF advantage with upright personally known faces occurs with both bilateral and unilateral presentation and is apparent down to the age of 7 years. The absence of any hemifield difference for naming familiar inverted faces replicates the results of the studies which have incorporated unknown inverted faces and suggests that both unknown and

known faces, when shown upside-down, are not processed asymmetrically. The non-significant half field effect with inversion also indicates that the LVF superiority for upright faces represents a special involvement of the right hemisphere in processing such faces.

With reference to the results of these tachistoscopic paradigms, investigation of inverted known and unknown faces was carried out in an attempt to replicate the above findings electrophysiologically. The half field studies described have shown no laterality effect with inversion and it was therefore expected that in right handed controls there would be no significant P300 amplitude difference between the right and left hemispheres in response to inverted face stimuli.

Brief procedure

Twenty-one right handed subjects were examined. The results are reported on 20, 9 males and 11 females, as one set of data was lost in error. All subjects were the same individuals (from the original group of 30) who participated in Experiment 1. Their ages ranged from 20 to 53 years, mean age 33.4 years. Each subject viewed two types of stimuli, inverted known and inverted unknown faces, the sets being alternated between subjects to overcome any order effect. The slides were the same as those presented upright, approximately 3 years previously, during Experiment 1. Although the inverted unknown faces had therefore been seen before the time delay of three years should have allowed substantial forgetting. Recordings were made from electrodes overlying the right and left posterior temporal, parietal and occipital regions, all referred to Fz.

Following presentation of each inverted known face subjects were requested to try and name the person. If they could not, they were asked

to say if they recognised the face (and if possible to give some clue to identification, e.g. occupation) or to state whether they had absolutely no idea who it was. At the end of the experiment each known face was presented upright in a small slide viewer and again the subject was requested to name the face, or if unable to, to say whether they recognised the person at all. The mean number of inverted and upright known faces, which were either named correctly, recognised but not named or not recognised at all, is given below.

	Named correctly	Recognised (not named)	Not recognised at all	Misnamed
Inverted known	20	4	16	2
Upright known	34	5	2	1

(Total number of slides = 42)

Results

Evoked potentials were again consistently recorded from each subject at all electrode sites under both conditions and the typical waveform replicates the response obtained in previous experiments. Tables 6:1 and 6:2 give the mean latencies and amplitudes for P100 and P300 respectively, at each electrode for the two types of stimuli.

The data from Experiment 3 conform to the same factorial analysis of variance (ANOVA) design used previously. In order to compare the dependent variables under the two conditions (inverted known and inverted unkown faces) an ANOVA was performed separately on each, namely P100 amplitude, P100 latency, P300 amplitude and P300 latency.

RIGHT HANDERS

INVERTED KNOWN AND UNKNOWN FACES

P100 AMPLITUDES AND LATENCIES

TABLE 6:1

		T6	P4	O2	T5	P3	O1
INVERTED KNOWN FACES	lat (ms)	113 (22.6)	111 (23.1)	110 (25.5)	110 (20.9)	109 (22.7)	109 (24.5)
	amp (uV)	7.3 (3.0)	6.4 (3.2)	9.0 (3.9)	6.5 (3.1)	5.5 (2.8)	8.7 (3.9)
INVERTED UNKNOWN FACES	lat (ms)	116 (21.3)	115 (22.2)	116 (22.2)	114 (22.2)	114 (23.9)	114 (22.9)
	amp (uV)	7.3 (3.5)	7.2 (3.3)	9.1 (4.7)	6.4 (3.7)	6.1 (3.6)	8.7 (4.9)

* Brackets indicate respective standard deviations

RIGHT HANDERS

TABLE 6:2

INVERTED KNOWN AND UNKNOWN FACES

P300 AMPLITUDES AND LATENCIES

		T6	P4	O2	T5	P3	O1
INVERTED KNOWN FACES	lat (ms)	288 (27.3)	288 (31.9)	290 (26.8)	284 (26.4)	285 (30.1)	287 (24.3)
	amp (uV)	13.3 (5.3)	10.7 (4.3)	13.8 (5.3)	12.8 (5.7)	9.2 (3.9)	12.8 (5.1)
INVERTED UNKNOWN FACES	lat (ms)	294 (28.5)	291 (33.4)	292 (30.7)	291 (30.5)	295 (32.6)	290 (26.9)
	amp (uV)	12.4 (5.7)	9.5 (4.7)	12.2 (6.0)	12.1 (6.5)	8.3 (4.2)	11.2 (5.8)

* Brackets indicate respective standard deviations

ANOVA: P100 Amplitude

Table 6:3 and Fig 6:4 present the ANOVA results for P100 amplitude, $p < 0.05$ again being regarded as significant in respect to the table of probabilities. The only significant effect is one of position, $F(2,34) = 17.2$, $p < 0.001$. From inspection of Fig 6:4 it can be seen that this is due to the amplitude of P100 being bilaterally of higher amplitude occipitally (8 to 9 uV) than in temporal and parietal regions (5 to 7 uV), with both conditions.

ANOVA: P100 latency

The ANOVA results for P100 latency are given in Table 6:5 and Fig 6:6. There were no significant general effects but position x sex proved significant, $F(2,36) = 3.79$, $p < 0.05$. Because this position x sex effect did not interact with any other variable the mean latencies of P100 at the different electrode positions have been calculated regardless of condition and laterality for males and females and are shown in the following table.

	Temporal	Parietal	Occipital
Females	109.9	107.3	105.4 ms
Males	117.3	118.6	121.3
Difference	7.4	11.3	15.9 ms

Although the male controls show prolonged P100 latencies compared to the females at all electrode positions, there was in fact no significant general effect of sex. The significant position x sex effect therefore appears to be due to the largest difference in P100 between the sexes, i.e. that which occurs in occipital regions, a difference of 15.9 ms.

P100 AMPLITUDE

TABLE 6:3

ANOVA Table of probabilities for Experiment 3

Inverted known and unknown faces (right handers)

Source	Degrees of Freedom	F	Probability	
Sex	1	2.05	0.1703	
Error	17			
Condition	1	0.11	0.7426	
Condition/Sex	1	0.64	0.4352	
Error	17			
Laterality	1	3.25	0.0891	
Laterality/Sex	1	0.02	0.8927	
Error	17			
Condition/Laterality	1	0.09	0.7739	
Cond/Lat/Sex	1	0.20	0.6587	
Error	17			
Position	2	17.20	0.0000	*
Position/Sex	2	0.37	0.6934	
Error	34			
Condition/Position	2	1.17	0.3218	
Cond/Pos/Sex	2	0.17	0.4975	
Error	34			
Laterality/Position	2	0.77	0.4707	
Lat/Pos/Sex	2	0.71	0.5005	
Error	34			
Cond/Lat/Pos	2	0.09	0.9125	
Cond/Lat/Pos/Sex	2	0.73	0.4905	
Error	34			

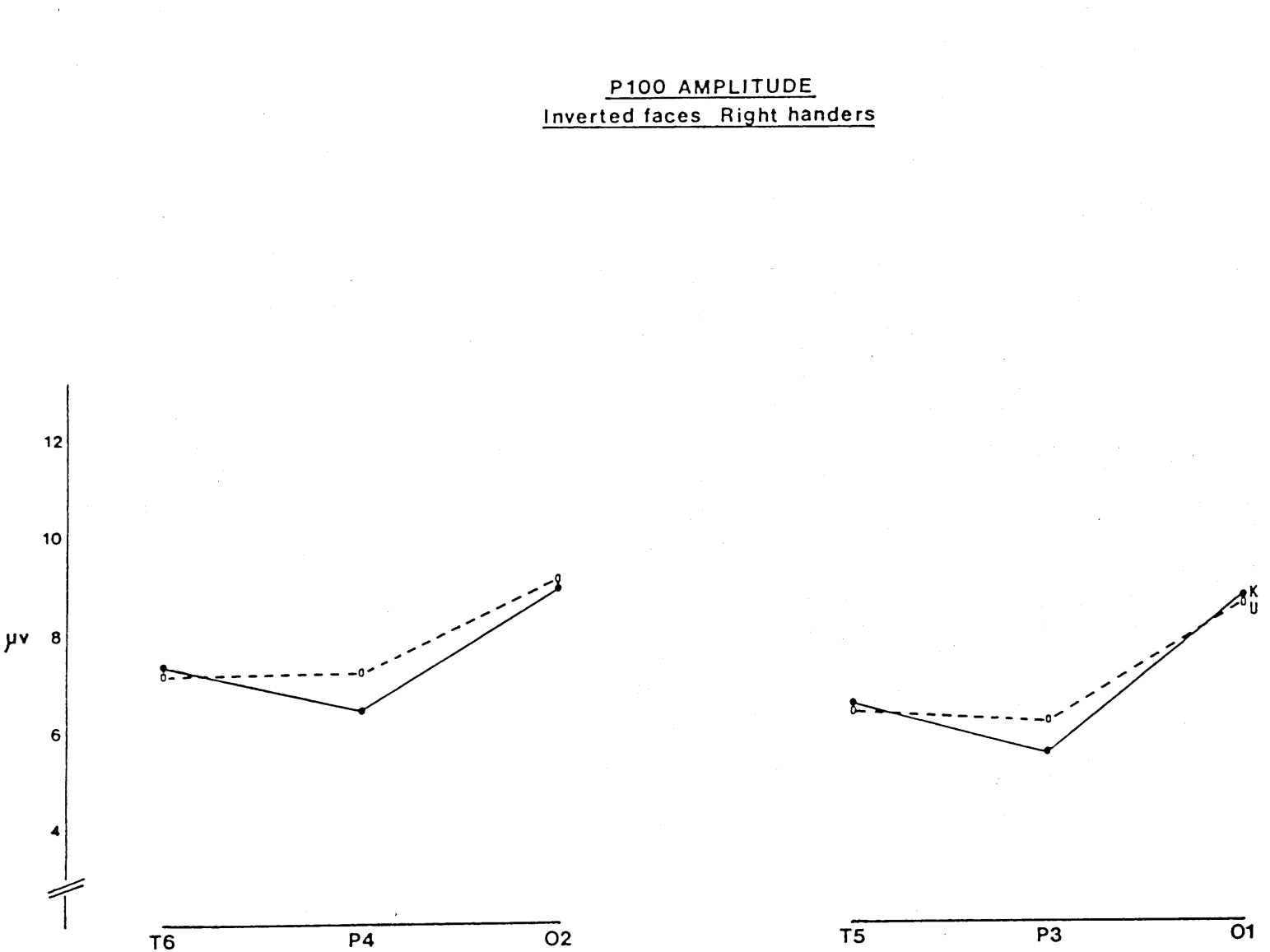


Fig 6:4 Amplitude (uV) of P100 at the six electrode positions for known inverted faces (solid line) and unknown inverted faces (dotted line).

P100 LATENCY TABLE 6:5

ANOVA Table of probabilites for Experiment 3

Inverted known and unknown faces (right handers)

Source	Degrees of Freedom	F	Probability	
Sex	1	1.68	0.2115	
Error	18			
Condition	1	1.71	0.2079	
Condition/Sex	1	1.50	0.2372	
Error	18			
Laterality	1	4.40	0.0503	
Laterality/Sex	1	0.01	0.9248	
Error	18			
Condition/laterality	1	0.16	0.6927	
Cond/Lat/Sex	1	0.81	0.3798	
Error	18			
Position	2	0.08	0.9253	
Position/Sex	2	3.79	0.0321	*
Error	36			
Condition/Position	2	0.22	0.8001	
Cond/Pos/Sex	2	0.12	0.8884	
Error	36			
Laterality/Position	2	1.04	0.3623	
Lat/Pos/Sex	2	0.01	0.9920	
Error	36			
Cond/Lat/Pos	2	0.47	0.6300	
Cond/Lat/Pos/Sex	2	0.43	0.6512	
Error	36			

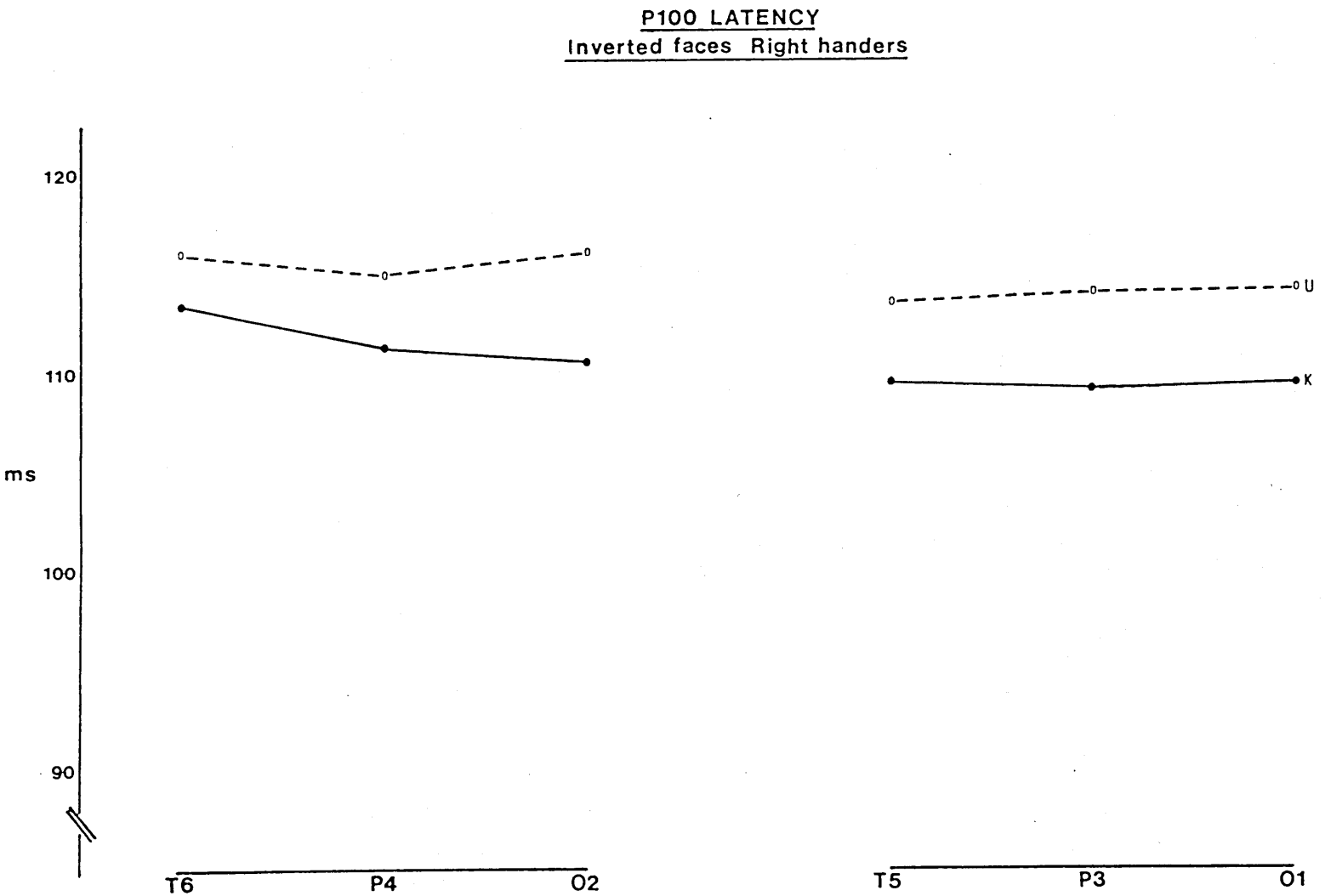


Fig 6:6 Latency (ms) of P100 at the six electrode positions for inverted known faces (solid line) and inverted unknown faces (dotted line).

ANOVA: P300 amplitude

Table 6:7 and Fig 6:8 show the results for P300 amplitude. The only significant effect was a general one of position, $F(2,34) = 27.8$, $p < 0.001$, due to P300 being of higher amplitude temporally and occipitally (11 to 13 uV) than parietally (8 to 10 uV). There was no significant condition effect (i.e. known inverted versus unknown inverted faces), $F(1,17) = 3.28$, $p = 0.0880$ and the laterality effect did not prove significant either, $F(1,17) = 2.45$, $p = 0.1357$.

ANOVA: P300 latency

P300 latency results are given in Table 6:9 and Fig 6:10. There were no significant general effects but condition x laterality x position x sex proved just significant, $F(2,36) = 3.78$, $p < 0.05$.

This analysis shows no significant effect between the conditions (in latency or amplitude of either P100 or P300) and so inverted known faces and inverted unknown faces seem to be processed in a similar manner. The results also show that although P300 again occurred with a small right hemisphere amplitude emphasis (right greater than left by 1 uV), this laterality effect did not prove significant. As the slides used in this experiment were exactly the same as those shown during Experiment 1 (apart from the inversion) and the same group of subjects participated, this lack of a significant right sided emphasis with inverted faces cannot be due to either the physical properties of the stimuli (e.g. contrast or luminance) or to the complexity of the material. The result therefore provides evidence to support the theory that inverted faces are processed more symmetrically and in a different way to upright faces.

In order to investigate the effect of inversion more fully the evoked potentials recorded in response to inverted known and unknown

P300 AMPLITUDE TABLE 6:7

ANOVA Table of probabilities for Experiment 3

Inverted known and unknown faces (right handers)

Source	Degrees of Freedom	F	Probability	
Sex	1	0.83	0.3755	
Error	17			
Condition	1	3.28	0.0880	
Condition/Sex	1	1.11	0.3070	
Error	17			
Laterality	1	2.45	0.1357	
Laterality/Sex	1	0.47	0.5013	
Error	17			
Condition/Laterality	1	0.16	0.6968	
Cond/Lat/Sex	1	2.68	0.1202	
Error	17			
Position	2	27.82	0.0000	*
Position/Sex	2	3.07	0.0594	
Error	34			
Condition/Position	2	1.99	0.1518	
Cond/Pos/Sex	2	3.25	0.0511	
Error	34			
Laterality/Position	2	1.34	0.2750	
Lat/Pos/Sex	2	2.20	0.1267	
Error	34			
Cond/Lat/Pos	2	0.22	0.8027	
Cond/Lat/Pos/Sex	2	1.56	0.2245	
Error	34			

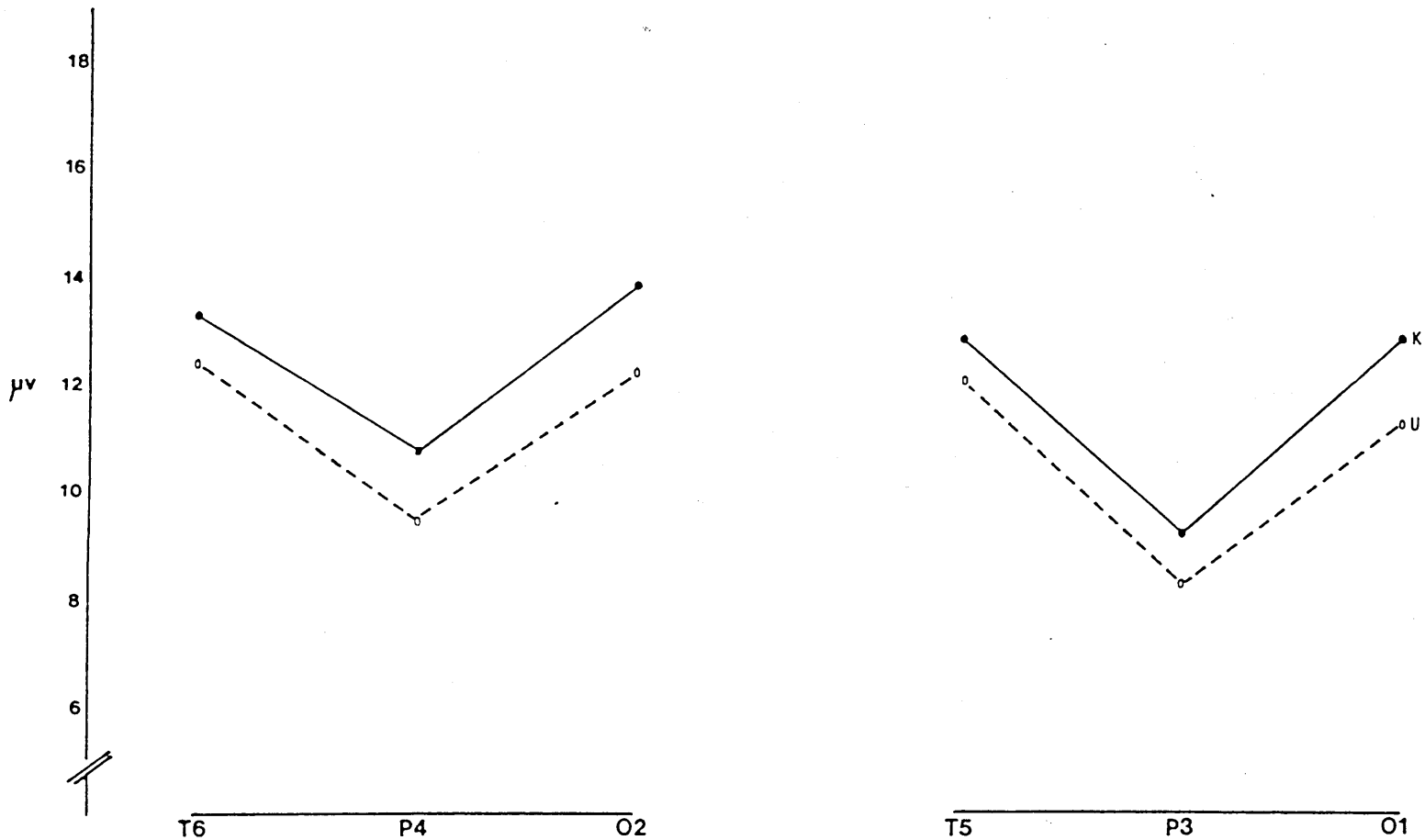


Fig 6:8 Amplitude (uV) of P300 at the six electrode positions for inverted known faces (solid line) and inverted unknown faces (dotted line).

P300 LATENCY

TABLE 6:9

ANOVA Table of probabilities for Experiment 3

Inverted known and unknown faces (right handers)

Source	Degrees of Freedom	F	Probabilitiy	
Sex	1	1.31	0.2675	
Error	18			
Condition	1	1.31	0.2675	
Condition/Sex	1	0.59	0.4514	
Error	18			
Laterality	1	3.13	0.0937	
Laterality/Sex	1	3.32	0.0850	
Error	18			
Condition/Laterality	1	0.49	0.4909	
Cond/Lat/Sex	1	0.75	0.3984	
Error	18			
Position	2	0.03	0.9699	
Position/Sex	2	1.93	0.1595	
Error	36			
Condition/Position	2	2.47	0.0984	
Cond/Pos/Sex	2	0.08	0.9199	
Error	36			
Laterality/Position	2	1.75	0.1887	
Lat/Pos/Sex	2	0.37	0.6959	
Error	36			
Cond/Lat/Pos	2	1.83	0.1757	
Cond/Lat/Pos/Sex	2	3.78	0.0323	*
Error	36			

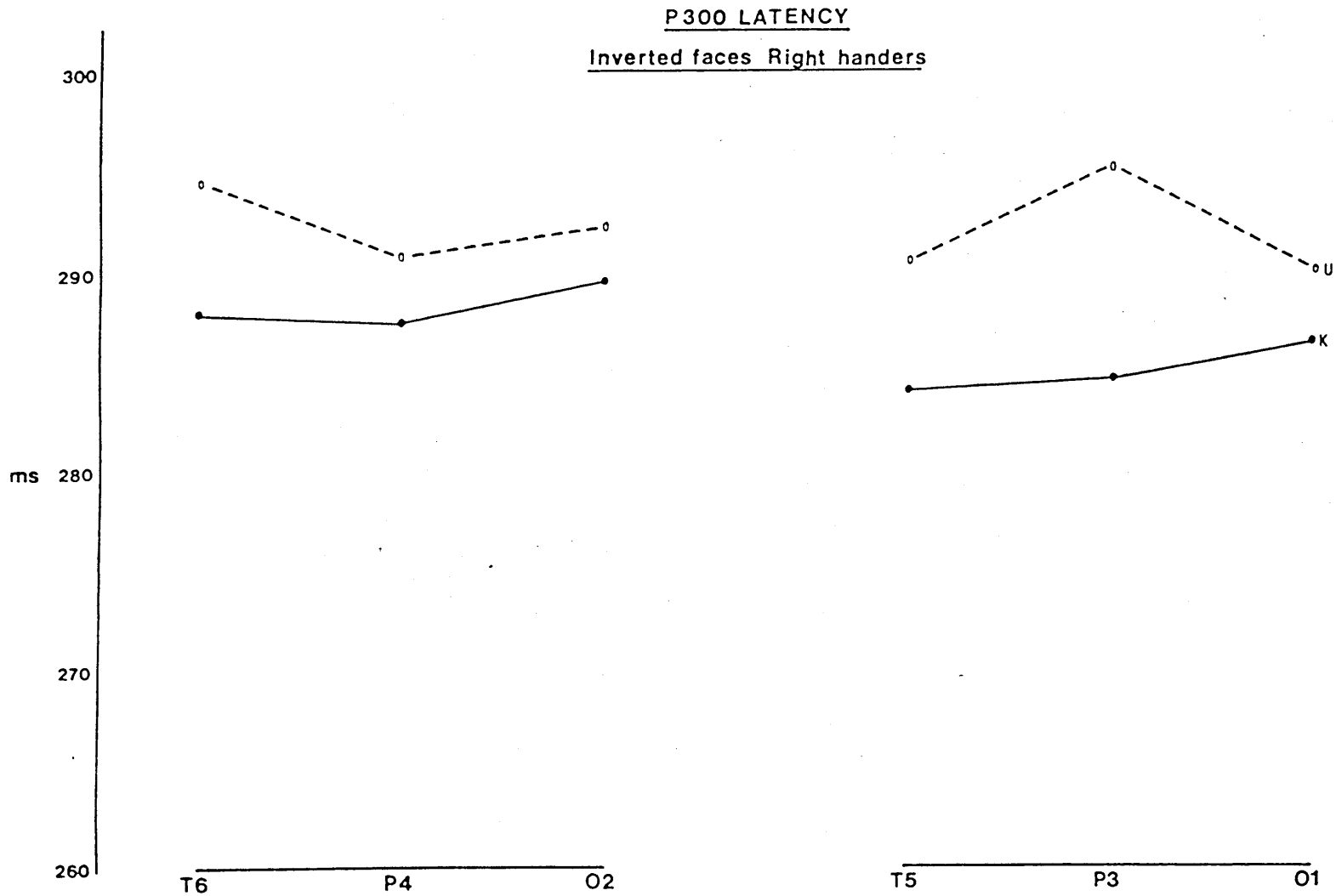


Fig 6:10 Latency (ms) of P300 at the six electrode positions for inverted known faces (solid line) and inveretd unknown faces (dotted line).

faces were compared with those obtained during Experiment 1 with upright known and unknown faces, again using an ANOVA design. Because the same sets of slides were used for both upright and inverted face conditions the physical properties of the stimuli remained identical and so it was expected that the ANOVAs for P100 amplitude and latency would not show any significant differences. For P300 amplitude however, it was predicted that there would be an interaction between laterality and inversion caused by upright faces producing a clear right hemisphere emphasis but P300 appearing with inverted faces more symmetrically, though still right greater than left.

ANOVA comparisons were performed separately on each of the four dependent variables, i.e. P100 amplitude, P100 latency, P300 amplitude and P300 latency. An effect was defined as a difference between the means of the upright and inverted face conditions. In order to prevent repetition of previously described results from the separate ANOVAs on upright faces and inverted faces, only the following effects have been reported:

i. A general effect of laterality

ii. A general effect of inversion (i.e. a difference between upright faces and inverted faces)

iii. An interaction between laterality and inversion

iv. An interaction between known/unknown and upright/inverted face conditions

A probability of $p < 0.05$ was again taken as significant in respect to the ANOVA tables.

ANOVA: P100 amplitude

Table 6:11 shows the results for P100 amplitude. There was no sig-

P100 AMPLITUDE

TABLE 6:11

ANOVA Table of probabilities for Experiment 3

Uprightknown and unknown faces versus Inverted known and unknown faces

Source	Degrees of freedom	F	Probability
Laterality	1	2.88	0.1081
Error	17		
Position	2	47.28	0.0000
Error	34		
Laterality/Position	2	0.72	0.4925
Error	34		
Inversion	1	1.86	0.1905
Error	17		
Laterality/Inversion	1	0.33	0.5751
Error	17		
Position/Inversion	2	3.43	0.0440
Error	34		
Laterality/Pos/Inversion	2	0.16	0.8526
Error	34		
Known v Unknown condition	1	0.22	0.6423
Error	17		
Laterality/Known v Unknown	1	2.33	0.1455
Error	17		
Position/Known v Unknown	2	0.45	0.6423
Error	34		
Lat/Pos/Known v Unknown	2	0.05	0.9485
Error	34		
Inversion/Known v Unknown	1	0.00	0.9512
Error	17		
Lat/Inverson/Known v Unknown	1	1.17	0.2948
Error	17		
Pos/Inversion/Known v Unknown	2	1.75	0.1890
Error	34		

nificant general effect of laterality or of inversion, and no interaction between these two variables. Similarly, there was no significant interaction between known/unknown and upright/ inverted conditions.

ANOVA: P100 latency

The results for P100 latency are given in Table 6:12. There was a significant general effect of laterality, $F(1,18) = 5.93$, $p < 0.05$, with the right hemisphere responding 1.6 ms slower than the left side. The right sided mean latency was 115.8 ms and the left, 114.2 ms. There was no significant general effect of inversion and no interaction between laterality and inversion or with the known/unknown versus upright/inverted conditions.

ANOVA: P300 amplitude

Table 6:13 shows the results for P300 amplitude. There was a significant general effect of laterality, $F(1,17) = 5.68$, $p < 0.05$, caused by P300 being overall 1.5 uV larger over the right hemisphere compared to the left. The mean right sided P300 amplitude was 15.5 uV and the left, 14.0 uV. A general effect of inversion also occurred, $F(1,17) = 36.82$, $p < 0.001$, due to a mean overall lower P300 amplitude of 11.5 uV with inverted faces compared to a mean of 18.0 uV with upright faces. There was however no significant interaction between inversion and laterality, $F(1,17) = 3.74$, $p = 0.0701$. In other words the analysis showed no difference in the right and left sided P300 amplitudes between upright and inverted faces.

The effect of inversion interacted with position, $F(2, 34) = 7.08$, $p<0.01$ and from the following Table it can be seen that this result is due to P300 occurring with a lower amplitude in the parietal region (compared to temporal and occipital areas) with both inverted and upright

P100 LATENCY

TABLE 6:12

ANOVA Table of probabilities for Experiment 3

Upright known and unknown faces versus Inverted known and unknown faces

Source	Degrees of freedom	F	Probability	
Laterality	1	5.93	0.0255	*
Error	18			
Position	2	0.06	0.9392	
Error	36			
Laterality/Position	2	1.39	0.2616	
Error	36			
Inversion	1	0.80	0.3819	
Error	18			
Laterality/Inversion	1	0.51	0.4849	
Error	18			
Position/Inversion	2	0.11	0.9001	
Error	36			
Laterality/Pos/Inversion	2	0.60	0.5550	
Error	36			
Known v Unknown conditions	1	1.95	0.1794	
Error	18			
Laterality/Known v unknown	1	0.82	0.3772	
Error	18			
Position/Known v unknown	2	0.51	0.6037	
Error	36			
Lat/Pos/Known v unknown	2	0.48	0.6253	
Error	36			
Inversion/Known v unknown	1	0.31	0.5816	
Error	18			
Lat/Inversion/Known v unknown	1	0.46	0.5072	
Error	18			
Pos/Inversion/Known v unknown	2	0.22	0.8000	
Error	36			

P300 AMPLITUDE TABLE 6:13

ANOVA Table of probabilities for Experiment 3

Upright known and unknown faces versus Inverted known and unknown faces.

Source	Degrees of freedom	F	Probability	
Laterality	1	5.68	0.0291	*
Error	17			
Position	2	38.35	0.0000	
Error	34			
Laterality/Position	2	0.20	0.8186	
Error	34			
Inversion	1	36.82	0.0000	*
Error	17			
Laterality/Inversion	1	3.74	0.0701	
Error	17			
Position/Inversion	2	7.08	0.0027	*
Error	34			
Laterality/Pos/Inversion	2	0.87	0.4286	
Error	34			
Known v unknown conditions	1	1.81	0.1962	
Error	17			
Laterality/Known v unknown	1	3.05	0.0989	
Error	17			
Position/Known v unknown	2	5.24	0.0104	
Error	34			
Lat/Pos/Known v unknown	2	2.69	0.0820	
Error	34			
Inversion/Known v unknown	1	0.59	0.4546	
Error	17			
Lat/Inversion/Known v unknown	1	1.49	0.2394	
Error	17			
Pos/Inversion/Known v unknown	2	0.11	0.8991	
Error	34			

faces, but more markedly with the latter.

	Temporal	Parietal	Occipital
Inverted	12.7	9.4	12.5
Upright	21.5	14.4	20.5

There was no interaction between known/unknown and upright/inverted conditions.

ANOVA: P300 latency

The results for P300 latency appear in Table 6:14. There was no general effect of laterality or of inversion and no interaction between these two variables or between the known/unknown and upright/inverted face conditions.

The results of this second ANOVA showed no difference between inverted and upright faces for P100 amplitude, P100 latency or P300 latency. Because the face slides were physically identical under the two conditions this result was expected for P100, substantiating the theory that this component is related to the physical parameters of a stimulus.

In contrast, the ANOVA for P300 amplitude showed a highly significant difference between upright and inverted faces, due to the amplitude generally being much lower with upside down faces (6 to 7 uV smaller). As mentioned previously, the physical conditions of the slides did not change, so this finding suggests that some factor associated with the cognitive processing of faces is altered with inversion. Although it might be thought that a face is equally complex whether upside down or upright, this may be true only if a face is processed in just the same way as any other type of complex pattern, rather than as a unique

P300 LATENCY TABLE 6:14

ANOVA Table of probabilities for Experiment 3

Upright known and unknown faces versus Inverted known and unknown faces

Source	Degrees of freedom	F	Probability
Laterality	1	1.60	0.2220
Error	18		
Position	2	0.22	0.8012
Error	36		
Laterality/Position	2	1.44	0.2495
Error	36		
Inversion	1	0.05	0.8230
Error	18		
Laterality/Inversion	1	0.35	0.5594
Error	18		
Position/Inversion	2	0.05	0.9496
Error	36		
Laterality/Pos/Inversion	2	1.46	0.2460
Error	36		
Known v unknown conditions	1	1.10	0.3081
Error	18		
Laterality/Known v unknown	1	0.00	0.9899
Error	18		
Position/Known v unknown	2	0.88	0.4226
Error	36		
Lat/Pos/Known v unknown	2	1.11	0.3147
Error	36		
Inversion/Known v unknown	1	0.45	0.5088
Error	18		
Lat/Inversion/Known v unknown	1	0.97	0.3377
Error	18		
Pos/Inversion/Known v unknown	2	1.49	0.2383
Error	36		

stimulus dependent on a certain orientation. It should be pointed out that subjects found the recognition of known inverted faces much more difficult than they anticipated, a fact reflected in the groups' overall poor performance of 48% correct recognition with inversion compared to 81% correct with upright faces. Inverting a face therefore does appear to alter its complexity in a cognitive sense, disturbing the usual recognition ability. However, the lower P300 amplitude seen in response to inverted faces cannot reflect "lack of recognition" for if so, unknown upright faces should in theory have been of lower amplitude than known upright faces, yet no difference was found. By ruling out physical properties, complexity (in a physical sense) and "recognition" as contributions towards an explanation for this amplitude difference, the only remaining factor seems to be vertical orientation or the "meaningfullness" of a face provided by an upright orientation. Such a conclusion clearly suggests that upright faces are indeed processed as unique stimuli and not just as any type of complex pattern.

The prediction of an interaction between laterality and inversion was not born out. Although there was an overall right hemisphere P300 amplitude emphasis this proved not to be significantly greater for upright than for inverted faces. The previous separate ANOVAs have shown (i) a highly significant right greater than left amplitude superiority with upright faces but (ii) no significant right/left P300 amplitude difference with inverted faces and so this negative result from the combined ANOVA seems somewhat suprising. However, it is explicable in terms of the size of the difference required for significance. For upright faces the interhemispheric difference was highly significant, the right sided P300 being 2.6 uV larger than the left. With inverted faces this asymmetry was still apparent but to a lesser degree, the right sided

amplitude emphasis being only 0.9 uV, a non-significant result. In the combined ANOVA the overall difference between these two asymmetries (i.e. 2.6 uV and 0.9 uV) was too small to be regarded as significant, probably due to individual subject variation. Because there is a clear trend in the difference between upright and inverted faces better differentiation might have been achieved by increasing the number of subjects and thereby increasing the power of the tests.

Returning to the previous discussion as to whether the difference in P300 amplitude with upright and inverted stimuli reflects a type of processing specific to upright faces as opposed to a general complex pattern recognition, it seemed worthwhile to compare the evoked potentials in response to inverted faces with those recorded with geometric designs. P100 proved similar in latency and amplitude on the last ANOVA between upright and inverted faces and so this component should show only the same variations that appeared between geometric designs and upright faces during Experiment 1, i.e. an earlier P100 with geometric designs compared to inverted faces. For P300 amplitude the previous analysis showed only a small right/left asymmetry with inverted faces (very similar to the results with geometric designs in Experiment 1) and so it was predicted that no significant laterality difference would appear between conditions. P300 latency proved similar between inverted and upright faces, but during Experiment 1 this component occurred earlier with geometric designs compared to faces, so a condition effect was expected due to this.

ANOVA comparisons were carried out separately on each of the four dependent variables, namely P100 amplitude, P100 latency, P300 amplitude and P300 latency. The results are shown respectively on Tables 6:15, 6:16, 6:17 and 6:18 with $p < 0.05$ being regarded as significant. Again, in

P100 AMPLITUDE

TABLE 6:15

ANOVA Table of probabilities for Experiment 3

Inverted known and unknown faces and geometric designs

Source	Degrees of freedom	F	Probability
Mean	1	124.45	
Error	17		
Laterality	1	7.47	0.0142
Error	17		
Position	2	18.65	0.0000
Error	34		
Laterality/Position	2	1.26	0.2956
Error	34		
Condition	2	1.51	0.2351
Error	34		
Laterality/Condition	2	0.21	0.8088
Error	34		
Position/Condition	4	2.29	0.0690
Error	68		
Laterality/Pos/Cond.	4	0.36	0.8377
Error	68		

P100 LATENCY

TABLE 6:16

ANOVA Table of probabilities for Experiment 3

Inverted known and unknown faces and geometric designs

Source	Degrees of freedom	F	Probability	
Mean	1	1140.75		
Error	18			
Laterality	1	5.73	0.0278	
Error	18			
Position	2	0.23	0.7969	
Error	36			
Laterality/Position	2	2.83	0.0725	
Error	36			
Condition	2	15.17	0.0000	*
Error	36			
Laterality/Condition	2	0.13	0.8768	
Error	36			
Position/Condition	4	0.23	0.9199	
Error	72			
Laterality/Pos/Cond	4	0.33	0.8562	
Error	72			

P300 AMPLITUDE TABLE 6:17

ANOVA Table of probabilities for Experiment 3

Inverted known and unknown faces and geometric designs

Source	Degrees of freedom	F	Probability	
Mean	1	121.97		
Error	17			
Laterality	1	3.07	0.0979	
Error	17			
Position	2	20.87	0.0000	
Error	34			
Laterality/Position	2	1.48	0.2417	
Error	34			
Condition	2	3.35	0.0471	*
Error	34			
Laterality/Condition	2	0.30	0.7412	
Error	34			
Position/Condition	4	1.90	0.1208	
Error	68			
Laterality/Pos/Cond	4	1.58	0.1895	
Error	68			

P300 LATENCY

TABLE 6:18

ANOVA Table of probabilities for Experiment 3

Inverted known and unknown faces and geometric designs

Source	Degrees of freedom	F	Probability	
Mean	1	2882.75		
Error	18			
Laterality	1	4.58	0.0464	
Error	18			
Position	2	0.19	0.8238	
Error	36			
Laterality/Position	2	0.19	0.8259	
Error	36			
Condition	2	5.68	0.0072	*
Error	36			
Laterality/Condition	2	0.36	0.7012	
Error	36			
Position/Condition	4	1.52	0.2053	
Error	72			
Laterality/Pos/Cond	4	1.44	0.2282	
Error	72			

order to avoid repetition, only a significant difference between the conditions (geometric designs, inverted known faces and inverted unknown faces) and any subsequent interactions have been reported.

ANOVA: P100 amplitude

There was no significant difference between the conditions and no relevant interactions.

ANOVA: P100 latency

There was a highly significant effect between the conditions, $F(2,36) = 15.17$, $p < 0.0001$ caused by P100 occurring earlier in response to geometric designs with an overall mean latency of 89 ms compared to 109 and 115 ms for inverted known faces and inverted unknown faces respectively. There were no significant interactions.

ANOVA: P300 amplitude

The effect of condition was just significant, $F(2,34) = 3.35$, $p < 0.05$. The overall mean amplitude of P300 for geometric designs was 13.1 uV, for inverted known faces 12.1 uV and for inverted unknown faces 10.9 uV. Because the previous analysis showed no significant amplitude difference between inverted known and inverted unknown faces the present significant condition effect must be caused by the difference in amplitude (2.2 uV) between geometric designs and inverted unknown faces. This condition effect did not interact with laterality, $F(2,34) = 0.30$, $p = 0.7412$ and there were no other significant differences.

ANOVA: P300 latency

There was a significant condition effect, $F(2,36) = 5.68$, $p < 0.01$ due to P300 occurring earlier at 270 ms with geometric designs compared to 287 and 292 ms with inverted known and inverted unknown faces respec-

tively. There were however no significant interactions.

This analysis confirmed the prediction of earlier latencies for P100 and P300 with geometric designs compared to inverted known and inverted unknown faces. As expected for P300 amplitude there was no difference in lateralisation between the conditions. However, there was a just significant general effect due to lower amplitude of P300 with inverted unknown faces than with geometric designs.

Discussion of Results

Taken together, the results from the last three analyses show that in respect to P100 there is no difference in the processing of inverted and upright faces. Because the physical parameters of the slides remained constant this result was not unexpected and confirms the hypothesis that P100 is related to physical stimulus properties.

Unlike P100, P300 did show a difference in amplitude between inverted and upright faces. With regard to lateralisation, faces shown upside down failed to produce the clear right sided emphasis previously observed with upright faces. As the slides did not differ physically this result substantiates the theory that P300 is correlated with cognitive rather than physical parameters. The lack of a clear asymmetry with inversion also suggests that the marked right hemisphere amplitude superiority with upright faces is to some extent related to vertical orientation, a finding which supports the results of the tachistoscopic half field studies by Leehey et al (1978), Leehey and Cahn (1979) and Young and Bion (1981).

There was also a marked general difference in the amplitude between

upright and inverted face conditions, P300 being much smaller with the latter and in fact more similar to (even of lower amplitude than) the values found with geometric designs. For P300, under each type of condition, the following table shows (i) the overall amplitude and (ii) the individual right and left hemisphere amplitudes with the difference between them. (The amplitudes have been calculated disregarding electrode position).

	P300 amplitude (uV)			
Condition	Overall	Right	Left	Difference
Upright known faces	17.6	18.9	16.3	2.6
Upright unknown faces	17.8	18.5	16.5	2.0
Inverted known faces	12.1	12.6	11.6	1.0
Inverted unknown faces	10.9	11.4	10.5	0.9
Geometric designs	13.1	13.6	12.8	0.8

The difference in amplitude between inverted and upright faces cannot be related to recognition ability because P300 showed no comparable amplitude difference between upright unknown ("unrecognisable") and upright known faces. This general amplitude decrease therefore also appears to be related to the orientation of the stimulus. It is important to emphasize that with inverted faces P300 amplitude occurred bilaterally reduced, not merely of lower amplitude on the right side but decreased over both hemispheres. Such a finding indicates that either the hypothetical cortical neurones, specific to upright faces, are not unique to the right hemisphere but are located within both hemispheres (though with a right sided emphasis) or that activation spreads bilaterally.

These conclusions drawn from the human scalp evoked response correlate well with the studies undertaken by the Neurosciences Group at St Andrews, Fife who have recorded bilaterally from individual neurones within the superior temporal sulci of the macaque. Although it is impossible to identify activity in the macaque which corresponds to the human P300, all neurones studied responded at latencies greater than 100 ms. Perrett and Rolls (1983) have found cells that respond to the sight of faces or other views of the human head but which remained unresponsive to a wide variety of control stimuli such as simple geometrical, or complex 3D objects. Cells selective for faces in the macaque have also been reported by Bruce, Desimone and Gross (1981). These cells tend to be found in close proximity to other cells of the same type, providing evidence that processing of a particular type of information tends to be clumped together rather than evenly spread through the temporal cortex. In a more recent investigation Perrett et al (1984) report that these cells respond at a longer latency and with reduced magnitude to inverted face views. Similar results were found with other conditions in which face perception was possible but difficult (e.g. with a green filter). While the latency shift for the filtered view was thought to reflect a decrease in luminance no explanation was offered for the changes described with inversion.

To summarise: As predicted, the comparison between inverted and upright faces showed no significant differences in P100 amplitude or latency. However this component did occur later, as expected, with inverted faces (109/116 ms) when compared to geometric designs (89 ms).

In contrast, inverted and upright faces produced dissimilar results for P300 amplitude. The clear right greater than left asymmetry

previously reported in Experiment 1 was not apparent with inversion, providing evidence that the right hemisphere superiority with upright faces is specific to vertical orientation, in keeping with the findings of tachistoscopic half field studies. P300 also showed a general amplitude reduction over both hemispheres with inverted faces when compared to upright faces, the values being similar to, and even less than, those found in response to geometric designs. This overall amplitude decrease with inversion suggests that bilateral representation must occur in the processing of a vertically orientated stimulus.

CHAPTER 7

EXPERIMENT 4

The evoked response to verbal stimuli in right handed subjects

So far, the experimentation of this thesis has been concerned with the investigation of a cerebral evoked potential asymmetry as a correlate of right sided, non-verbal visual processing. However, in Chapter 1, it was briefly noted that considerable neuropsychological data have shown that both cerebral hemispheres in man assume a role in governing cognitive behaviour and that there is clear evidence of perceptual and memory mechanisms for verbal material being dependent on cortical structures in the dominant, usually left, hemisphere. Further exploration of cerebral lateralisation with regard to linguistic function, using evoked potential techniques, would now seem of value. Before reviewing the results of previous E.P. studies on this topic it is necessary to present a general background outlining the evidence for localisation and lateralisation of language with particular reference to the difference in processing between auditory and visual presentation of verbal material.

Localisation of language function.

The most significant discovery leading to the notion of cerebral dominance was the finding by Broca, Dax and others of a strong relationship between lesions of the left hemisphere and disorders of language, namely difficulty in expression, comprehension, reading and writing.

Broca (1861) investigated two cases of aphasia with post mortem examination and discovered that lesions restricted to the posterior portion of the frontal lobe resulted in deficits in the ability to use words. He also observed that lesions of a similar location in the non-dominant hemisphere did not produce such detrimental effects and therefore subsequently linked the left hemisphere with language function. The type of language defect he reported, now termed Broca's aphasia, is characterised by slow and laborious speech with difficulty in articulation but correct pronunciation. Understanding of spoken or written material is relatively well preserved. It would appear that the affected area has a major role to play in phonological and syntactic aspects of language generation.

In 1865 Dax published his father's paper recording the association of right hemiplegia with speech disorders and in 1874 Wernicke associated lesions limited to the posterior and lateral portions of the temporal lobe of the dominant hemisphere with a failure to understand language and a deficit in language production. The individual with a lesion in Wernicke's area can produce quite lengthy sentences that are syntactically correct but totally devoid of meaning. Whereas lesions in Broca's area are not accompanied by deficits in understanding of spoken or written language, the patient with Wernicke's aphasia suffers from severe loss of understanding of verbal material although perception of other non- vocal auditory signals is apparently normal (Geschwind, 1970; Goodglass, 1972).

The mapping of speech areas has been based on the observations of language interference caused by brain disease, penetrating head injuries, surgical excision and electrical stimulation of the exposed cortex. As

early as 1917 Marie and Foix mapped the region of the left hemisphere, which they believed to be necessary for speech, from evidence of post-mortem studies and cerebral trauma. Inferences from traumatic lesions have also been drawn by Golstein (1942), Luria (1947), Conrad (1954) and Russell and Espir (1961). In Conrad's report motor speech deficits predominate with damage to both margins of the central sulcus, extending frontally, while sensory and amnesic deficits occur with parieto-occipital injury. However, material from both Conrad (1942) and Russell and Espir (1961) show a somewhat random scatter of lesions with an overlap between aphasia-producing and aphasia-free locations.

Penfield and Roberts (1959) have also reported the findings from electrical stimulation of the cerebral cortex during surgical interventions. Their cortical map, showing points of stimulation affecting motor speech, confirms the impression gained from other maps (Conrad, 1954; Russell and Espir, 1961). However, the relevance of these electrical stimulation experiments must remain limited because the stimulus interferes abnormally with brain function. Activity is initiated on the surface of the cortex from a single anatomical location whereas in the normal state activity for speech may consist of ongoing activity in various parts of the brain including modulation of impulses in deeper structures.

There is evidence that the processing of visually presented verbal material has a different area of cerebral localisation compared to aurally presented words. Such information comes from the study of patients with the uncommon syndrome of alexia without agraphia, a condition in

which there is complete loss of the ability to read (including what the patient himself has written) but retained ability to write both spontaneously and to dictation. The rare occurrence of this syndrome is substantiated by the infrequent appearance of autopsied cases; a review by Benson and Geschwind (1969) lists only seventeen taken from the literature between 1890 and 1966. This study indicates that pathologically, the occipital region and the corpus callosum are the main areas of involvement. With only one exception the left occipital lobe was implicated in all cases. However, more specific localisations were somewhat variable but usually included the inner and under surface of the occipital lobe, essentially the area dependent upon the posterior cerebral artery for vascular supply. Infarction or "involvement" of the corpus callosum was described in nine patients. Benson and Geschwind (1969) point out that it could also have been present in the other cases because infarction of the tightly packed callosal white matter may not produce the grossly obvious degenerative changes that are seen after involvement of cortical or subcortical tissues. However, infarction of the corpus callosum may not be essential for producing the syndrome of alexia because deep white matter destruction in the left medial occipital region could just as readily disconnect the left hemisphere language areas from right sided visual processing.

A number of post-surgical cases of alexia without agraphia, secondary to lateral parieto-occipital pathology, have been recorded (Warrington and Zangwill, 1957; Kinsbourne and Warrington, 1964). The pathology of these cases was diverse including tumour and intracerebral

haematoma and the exact location of occipital involvement remains unknown because no post-mortem follow up was available. However, these reports raise the possibility of a second anatomical localisation for the production of reading disturbance without agraphia, but should, at present, remain conjectural until better clinical and pathological proof is presented. It would seem that the only consistently demonstrated pathology includes the dominant occipital lobe and the connections of the non-dominant visual association areas with the dominant speech areas.

Lateralisation of language: evidence from patient studies.

The development of hemispherectomy for infantile hemiplegia by Krynauw (1950) has allowed assessment of the effects on speech of removal of either hemisphere in the immature brain and reports show that there is continuing development of language function after right or left lobe removal. Gardner, Karnosh, McClure and Gardener (1955) and Hillier (1954) describe children with functional speech after left hemispherectomy, attributed to subsequent language development within the "non-dominant" hemisphere. However, there is general agreement that in the adult this plasticity is largely lost and dominant hemispherectomy has been discouraged. There are therefore only a limited number of cases recorded in the literature. Zollinger (1935) and Crockett and Estridge (1951) report speech and verbal comprehension (although severely impaired) to be present after left hemispherectomy in three patients. Smith (1966) describes a 47 year old right handed man in whom the left cerebral lobe was removed for glioma. The patient was studied during the first seven months after surgery. In the immmediate post-operative period he showed

severe receptive and expressive aphasia and at seven months, although verbal comprehension had slowly improved, he remained unable to speak voluntarily most of the time except for occasional propositional speech. As receptive language was less impaired and showed greater recovery than expressive language, Smith concludes that hemisphere functions appear to differ quantitatively rather than qualitatively.

Further evidence for the lateralisation of language comes from the four right handed commissurectomised patients reported by Sperry, Gazzaniga and Bogen (1969). Verbal material can be visually presented selectively to each hemisphere using the method described in Chapter 1. Under these testing conditions the patient can read and describe material of various kinds in the right half field (left hemisphere) at a level substantially the same as before surgery. However, commissurectomised patients remain consistently unable to describe, in speech or writing, stimuli which are presented to the left side of the vertical meridian (right hemisphere). Further analysis indicates that the difficulty with the left half-field of these patients is not due to a defect in vision but is a defect in verbal communication because when simple material or other non-verbal responses are used to demonstrate comprehension, it is clear that stimuli presented in the left half-field are seen and can be recognised, learned and remembered.

This study suggests that the right hemisphere of these patients is practically speechless. However, in a more recent investigation of six commissurectomised patients by Teng and Sperry (1973), (which in fact incorporates the same four patients just described by Sperry, Gazzaniga

and Bogen), some evidence has been obtained for right hemisphere verbalisation. Patients were shown tachistoscopically either letters or digits and were asked to identify them manually or verbally. Correct (or essentially correct) verbal identifications were made for 20% of the letters and 35% of the digits during left field presentation. Such findings demonstrate an above chance level (about 4% for letters and 10% for digits) of verbal identification for left field stimuli, even though the general performance level was still inferior to that from the right field. The results are compatible with the clinical observations by Smith (1966) regarding speech after left hemispherectomy.

Levy, Trevarthen and Sperry (1972) similarly point out a contradiction to the previously reported "typical responses" of these patients. When shown bilaterally presented chimeric stimuli, 3 out of 5 patients correctly described or named both left and right halves well above chance level. They conclude that if verbalisation indeed came from the right hemisphere such results presumably reflect the effects of post-operative training and re-education.

Lateralisation of language: evidence from normal subjects.

On a similar basis to the investigations into processing of non-verbal material, experimental evidence regarding language related hemisphere asymmetries in normal subjects has largely rested upon the demonstration of differential percentages of recognition following tachistoscopic presentation of such stimuli. The interpretation of results rests on the assumption that stimuli are perceived more easily if they have direct access, via the crossed sensory pathways, to the hemisphere that specializes in processing them. Such tachistoscopic displays have

generally been classified as either unilateral (successive) or bilateral (simultaneous). In the typical unilateral design a subject is instructed to focus upon the central position of the display field and following a brief interval, is then shown a stimulus to the right or the left of this central point. Cortical processing is subsequently assessed by asking the subject to identify the stimulus using either recall or recognition measures. Bilateral designs involve an essentially similar methodology with the exception that two or more stimuli are simultaneously presented, one to the right and one to the left of fixation. From its inception unilateral tachistoscopic presentation, in right handers, has consistently demonstrated a strong right visual field (i.e. left hemisphere) recognition superiority for verbal material, both with single letters (Bryden, 1965 and 1973; Kimura, 1966; Rizzolatti, Umilta and Berlucchi, 1971; Higenbottam, 1973) and single digits (Hines and Satz, 1971; Geffen, Bradshaw and Wallace, 1971).

Despite these clear and consistent results, bilateral verbal displays produced opposite findings with simultaneous exposures resulting in more accurate recognition in the left visual field, a right as opposed to a left hemisphere preference (Crosland, 1931; Heron, 1957). It was not until 1971 that McKeever and Huling (1971) resolved these differences by initiating an objective control of fixation, replacing the standard fixation point with a digit, which the subject was required to report prior to any peripheral identifications. This addition was employed to control for directional scanning which usually favours the left in simultaneous half-field stimulation because when information is presented at the same time to both half-fields the one on the left is "looked at" and reported first resulting in a left visual half field superiority.

Introduction of controlled fixation helped to resolve unilateral and bilateral disparities and subsequently the left hemisphere was shown to respond more accurately to verbal stimuli with both types of experimental design.

While single letters and digits are certainly language symbols they have little connotative meaning compared to words. Several studies have therefore investigated visual field differences using meaningful words as stimuli, with both unilateral presentation (Hilliard, 1973; Hines, 1976; Bradshaw, Gates and Nettleton, 1977) and bilateral displays (Mackavey, Curcio and Rosen, 1975; Klein, 1976). Some such studies have also compared hemispheric differences in processing different categories of words. Viewing single syllable words (nouns, pronouns, adjectives, verbs and adverbs), a series of random consonants (e.g. fxzt, jcfr) and phonologically legal nonwords, homophonous with real words (e.g. kirl, fale) Bradshaw et al (1977) found right handed males to be significantly faster and more accurate in the right visual field to all types of stimuli. The right field latency superiority for right handed females proved non-significant. Incorporating both unilateral and bilateral designs into one study and presenting familiar and unfamiliar verbs, abstract nouns and concrete nouns, Hines (1976) has reported a significantly greater right visual field recognition accuracy under all conditions. The familiar abstract nouns showed a greater right visual field superiority than did the familiar concrete nouns and Hines suggests that the decreased asymmetry for the concrete nouns may be due to recognition of these words by both the right and the left hemispheres. A larger right half field asymmetry for abstract over concrete nouns has also been shown by Ellis and Shepherd (1974).

Mackavey et al (1975) have pointed out that the horizontal orient-

ation of words in these tachistoscopic paradigms may actually favour the right half field because words presented in the left visual field originate further away from the fixation point (e.g. 4 degrees) than do those shown in the right visual field (e.g. 1 or 2 degrees). However, in an experiment incorporating horizontal and vertical placement of common nouns, a right hemi-field recognition advantage was found under both conditions. The same result also consistently occurred with long and short exposure durations and even without fixation control, demonstrating that the right visual field superiority for words is extremely robust.

Lateralisation of language : evoked potential studies.

The use of averaged evoked potential techniques for the study of language organisation has become increasingly popular in the past few years with the expectation that electrophysiological results would closely parallel the asymmetries described with tachistoscopic displays. However, the majority of such studies have been exclusive to the auditory modality using speech stimuli and only a small number of investigations incorporating visual presentation of language material have been described. The stimuli have consisted of either single letters, single digits or individual words. Courchesne, Courchesne and Hillyard (1978), displaying letters and digits in a task in which adult subjects had to count target slides and disregard background stimuli, have reported a P300 in response to all categories of slides, whether target, non-target, or slightly or highly deviant from the background sequence. Recording from midline electrodes (Fz, Cz and Pz) referred to the right mastoid they describe three main peaks with latencies of 90-150 ms, 160-280 ms and 300-600 ms ("P300"). In an identical experiment with children aged 6 to 17 years, Courchesne (1978) reports similar findings but notes that

P300 latencies decrease with age, suggesting that the speed of verbal processing increases with age. In both these studies symmetry was not assessable due to the use of midline electrodes only.

Comparing the evoked potential to single letters and random shapes in twenty right handed males with right and left occipital electrodes referred to the earlobe, Mancuso, Lawrence, Hintze and White (1979) report earlier latencies on the left side for peak latencies in the 100 to 300 ms range for verbal stimuli. However, their single illustration does not depict any well defined components and the results did not reach statistical significance. Shelburne (1972) presented three letter words and three letter nonsense trigrams (with letters shown consecutively) to eight right handed subjects whose task was to press a switch with the right hand if the letters spelt a word. The electrodes were placed at Cz, P4, P3, O2 and O1, all referred to linked mastoids. No detailed description is given of the evoked potential during the 750 ms post stimulus analysis time but "latencies and amplitudes of prominent peaks and troughs were measured". No consistently reliable differences were found between the responses to word stimuli and nonsense stimuli or between right and left hemispheres. Identical results were obtained using the same experimental procedure with twenty children of mean age 10 years (Shelburne, 1973). Buchsbaum and Fedio (1969) presenting three letter words (familiar nouns, verbs and adjectives), random dots and patterns, in an experiment in which the subjects were not required to perform a task, found the latency of a positive component at 190-280 ms to be earlier by 24 ms for all types of words compared to the non-verbal stimuli. Recording from occipital leads (O2 and O1) referred to the ipsilateral earlobes they observed no significant latency differences

between right and left leads but using a complicated computational technique to derive a discrimination index in order to investigate hemispheric asymmetry they state "waveforms for verbal and non-verbal stimuli were more different from the left hemisphere than from the right". Preston (1979) recorded from eighteen right handed subjects who viewed three letter words and nonsense patterns matched for physical properties, their only task being to make a mental count of a particular word. Electrodes were placed over right and left occipital and parietal areas (O2, O1, P4 and P3) referred to the ipsilateral mastoid. Only the 350-500 ms post stimulus period was analysed at 11 sample points, 16 ms apart. The results showed a significantly higher amplitude over the left parietal area compared to the right parietal region (mean difference 2.6 uV) with real words but not with nonsense words. Occipital leads showed no asymmetry which is in keeping with the results of two earlier studies (Mancuso et al, 1979; Buchsbaum and Fedio, 1969).

The evoked potentials to sequential words of a sentence have also been investigated. Friedman, Simpson, Ritter and Rapin (1975) presented slides of words consecutively, each block comprising six words which made a sentence, to eight right handers whose task was to report the second word shown in a trial. The first grapheme of the second word was omitted so that the subject did not know the meaning of the second word until the last word was presented, e.g. the -eel is on the shoe. With electrodes at Cz and over the right and left temporo-parietal regions referred to the nose they recorded four major components at 140 ms, 220 ms, 280 ms and 300-600 ms, (P300). Friedman et al noted the presence of a P300 wave to all the words of a sentence regardless of whether or not they delivered information to the subject. However, there were no significant amplitude asymmetries in any of the components. Kutas and Hillyard (1982) have

carried out a study of similar design with sentences (consisting of seven words) presented one word at a time. Half the sentences were completed by a semantically appropriate word and half by an inappropriate word, e.g. there are many people in the wallet. Recording with a linked mastoid reference from Cz, C3, C4, T3, T4 and two symmetrical temporo-parietal electrodes over Wernicke's area, they describe three components at 120-150 ms, 180-250 ms and 400-700 ms and note that these responses were present with all words. For words 1 to 6 they found a left greater than right amplitude asymmetry of the 400-700 ms component in temporo-parietal leads whereas with the 7th word this wave was of higher amplitude on the right. No other electrode positions showed a hemisphere difference.

Although these studies report conflicting evidence regarding hemisphere asymmetries in response to verbal stimuli, they do provide a strong indication of an existing late component between 300 and 700 ms. The present experiment was therefore undertaken to substantiate the occurrence of P300 to verbal material and to investigate any subsequent asymmetry in a group of right handed subjects who had, collectively in an earlier experiment, shown a clear right hemisphere amplitude superiority to non-verbal stimuli.

It was expected that a P300, perhaps showing considerable variability in latency, would be recorded in response to slides of common words. A marked amplitude asymmetry of this component seemed doubtful considering the previous equivocal reports, but if present, lateralisation was likely to be left greater than right in the right handed subjects. It was hoped that the current use of simultaneous recordings from temporal, parietal and occipital areas would provide a greater probability of detecting any small amplitude asymmetries compared to the

previously reported studies which confined electrodes to parietal and occipital (or just occipital) regions only.

Brief procedure:

Fifteen right handed subjects, 9 females and 6 males, participated. All subjects were the same individuals (from the original group of thirty) who took part in Experiment 1. Their ages ranged from 20 to 53 years, mean age 35 years. Each subject viewed one set of slides comprising 41 common words (see Appendix C), centered photographically and consisting of white letters on a black background. The slides were presented for two seconds at random intervals and the subjects were requested to fixate the centre of the screen. Recordings were made from right and left parietal, occipital and posterior temporal electrodes with Fz acting as the reference.

Results:

Again, evoked potentials were recorded consistently from each subject at all electrode sites. Tables 7:1 and 7:2 show the mean amplitude and latencies for P100 and P300 respectively at each electrode position. The data from this experiment conform to the same factorial analysis of variance (ANOVA) design used previously. ANOVA was therefore performed separately on each dependent variable, namely P100 amplitude, P100 latency, P300 amplitude and P300 latency.

ANOVA: P100 amplitude

Table 7:3 and Fig 7:4 present the ANOVA results for P100 amplitude, with $p < 0.05$ again being regarded as significant in respect to the table of probabilities. There were no significant effects.

P100 LATENCIES AND AMPLITUDES

TABLE 7:1

VERBAL STIMULI Right handers

	T6	P4	O2	T5	P3	O1
Lat	93.7 (20.8)	89.9 (23.6)	94.2 (23.8)	90.2 (22.3)	92.3 (23.7)	90.9 (24.5)
Amp	4.9 (2.4)	4.7 (2.7)	5.7 (3.4)	4.3 (2.3)	3.7 (2.3)	4.4 (2.5)

Brackets indicate respective standard deviations

P300 LATENCIES AND AMPLITUDES TABLE 7:2

VERBAL STIMULI Right handers

	T6	P4	O2	T5	P3	O1
Lat	292.3 (40.6)	289.3 (38.9)	290.3 (38.9)	294.3 (47.8)	294.6 (46.6)	293.3 (48.1)
Amp	8.8 (3.8)	8.0 (3.3)	9.4 (3.8)	9.9 (5.4)	7.7 (4.6)	9.4 (4.8)

Brackets indicate respective standard deviations

P100 AMPLITUDE TABLE 7:3

ANOVA Table of probabilities for Verbal stimuli

Source	Degrees of freedom	F	Probabilities
Sex	1	0.03	0.8687
Error	12		
Laterality	1	3.45	0.0878
Laterality/Sex	1	0.55	0.4740
Error	12		
Position	2	1.49	0.2458
Position/Sex	2	0.17	0.8430
Error	24		
Laterality/Position	2	0.96	0.3961
Laterality/Pos/Sex	2	0.62	0.5450
Error	24		

P100 AMPLITUDE Verbal stimuli

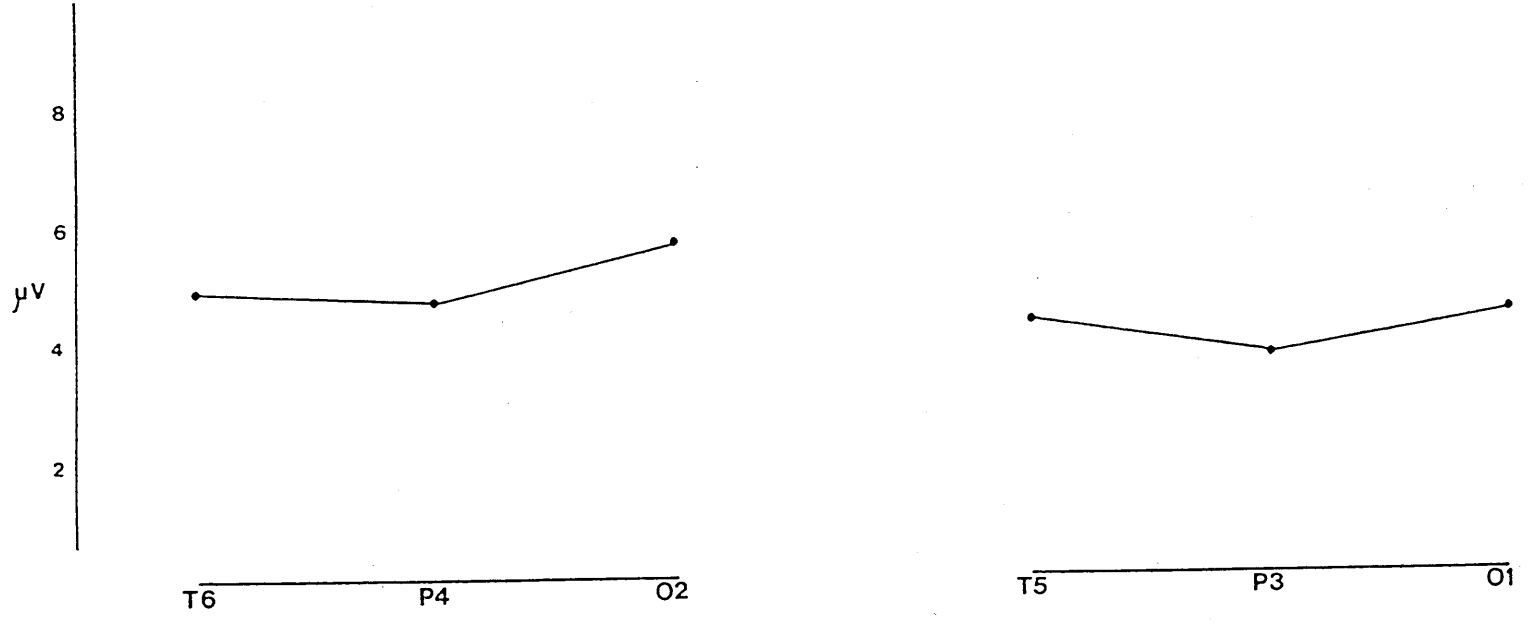


Fig 7:4 Amplitude (uV) of P100 at the six electrode positions in response to slides of words.

P100 LATENCY TABLE 7:5

ANOVA Table of probabilities for verbal stimuli

Source	Degrees of freedom	F	Probabilities
Sex	1	0.79	0.3914
Error	12		
Laterality	1	2.13	0.1702
Laterality/Sex	1	1.89	0.1948
Error	12		
Position	2	0.22	0.8026
Position/Sex	2	0.08	0.9275
Error	24		
Laterality/Position	2	1.39	0.2682
Laterality/Pos/Sex	2	0.95	0.4020
Error	24		

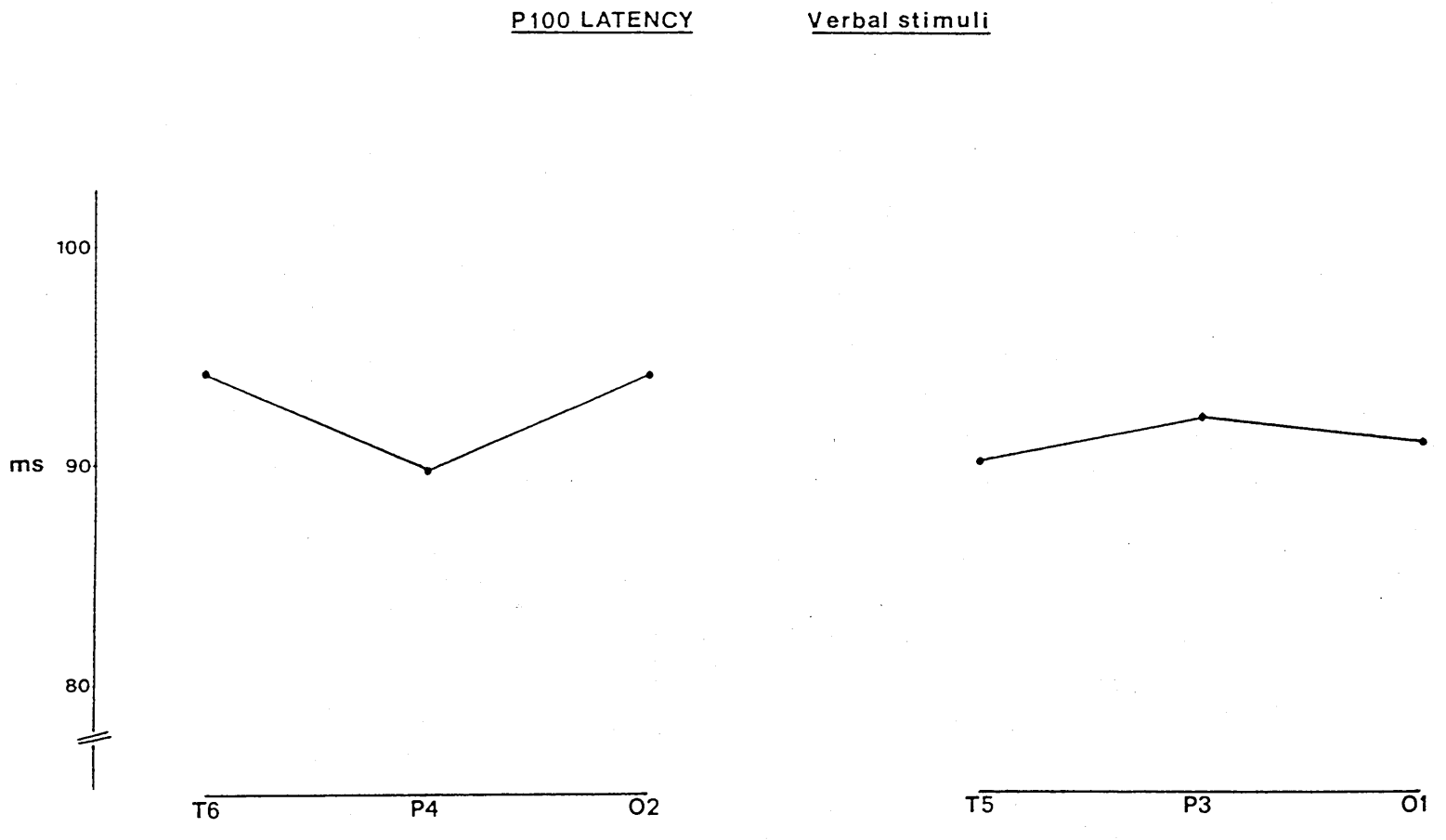


Fig 7:6 Latency (ms) of P100 at the six electrode positions in response to slides of words.

P300 AMPLITUDE TABLE 7:7

ANOVA Table of probabilities for Verbal stimuli

Source	Degrees of freedom	F	Probabilities
Sex	1	1.33	0.2692
Error	13		
Laterality	1	0.03	0.8616
Laterality/Sex	1	1.38	0.2611
Error	13		
Position	2	2.68	0.0874
Position/Sex	2	1.16	0.3300
Error	26		
Laterality/Position	2	1.75	0.1944
Laterality/Pos/Sex	2	3.37	0.0498 *
Error	26		

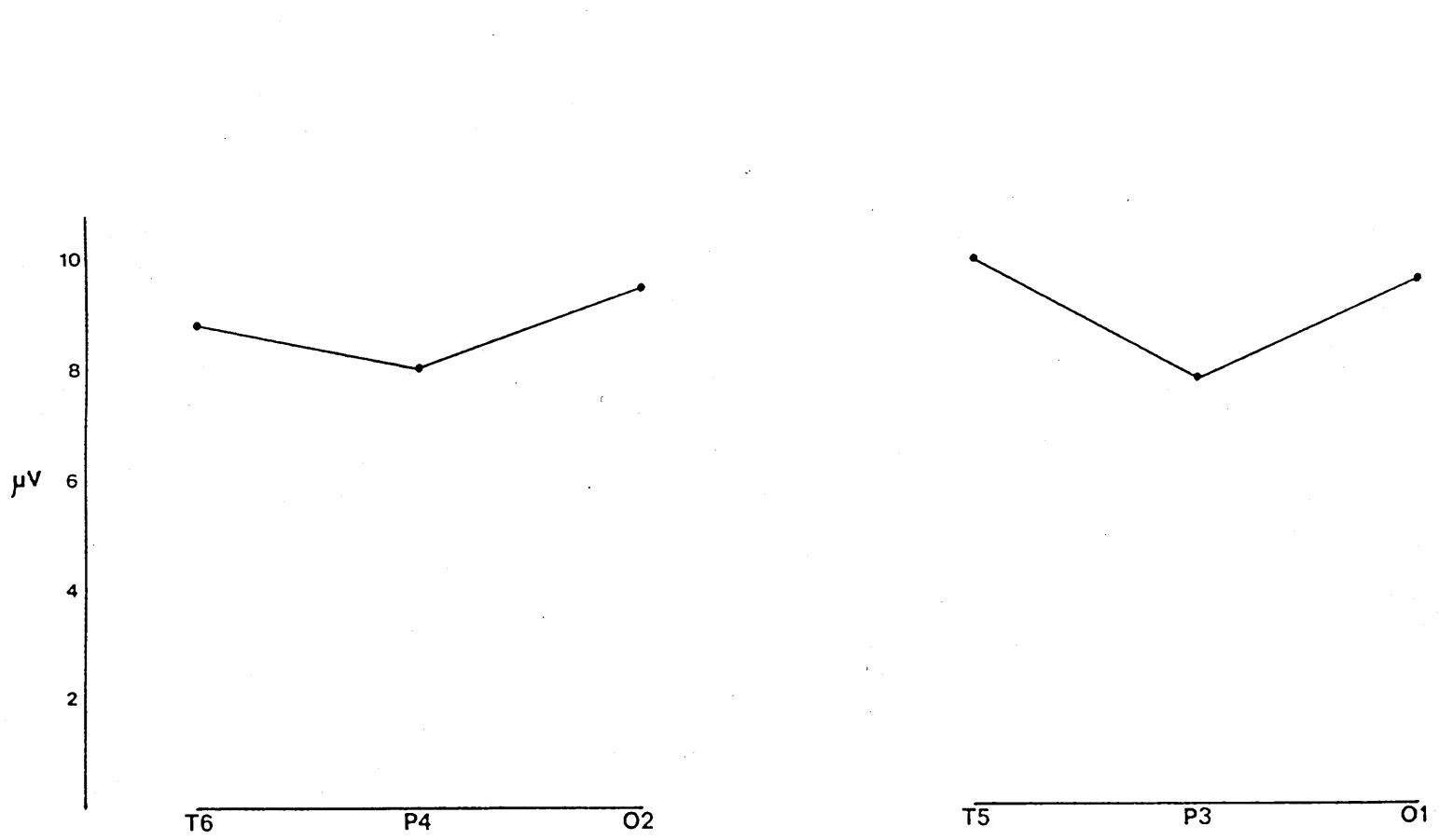


Fig 7:8 Amplitude (uV) of P300 at the six electrode positions in response to slides of words.

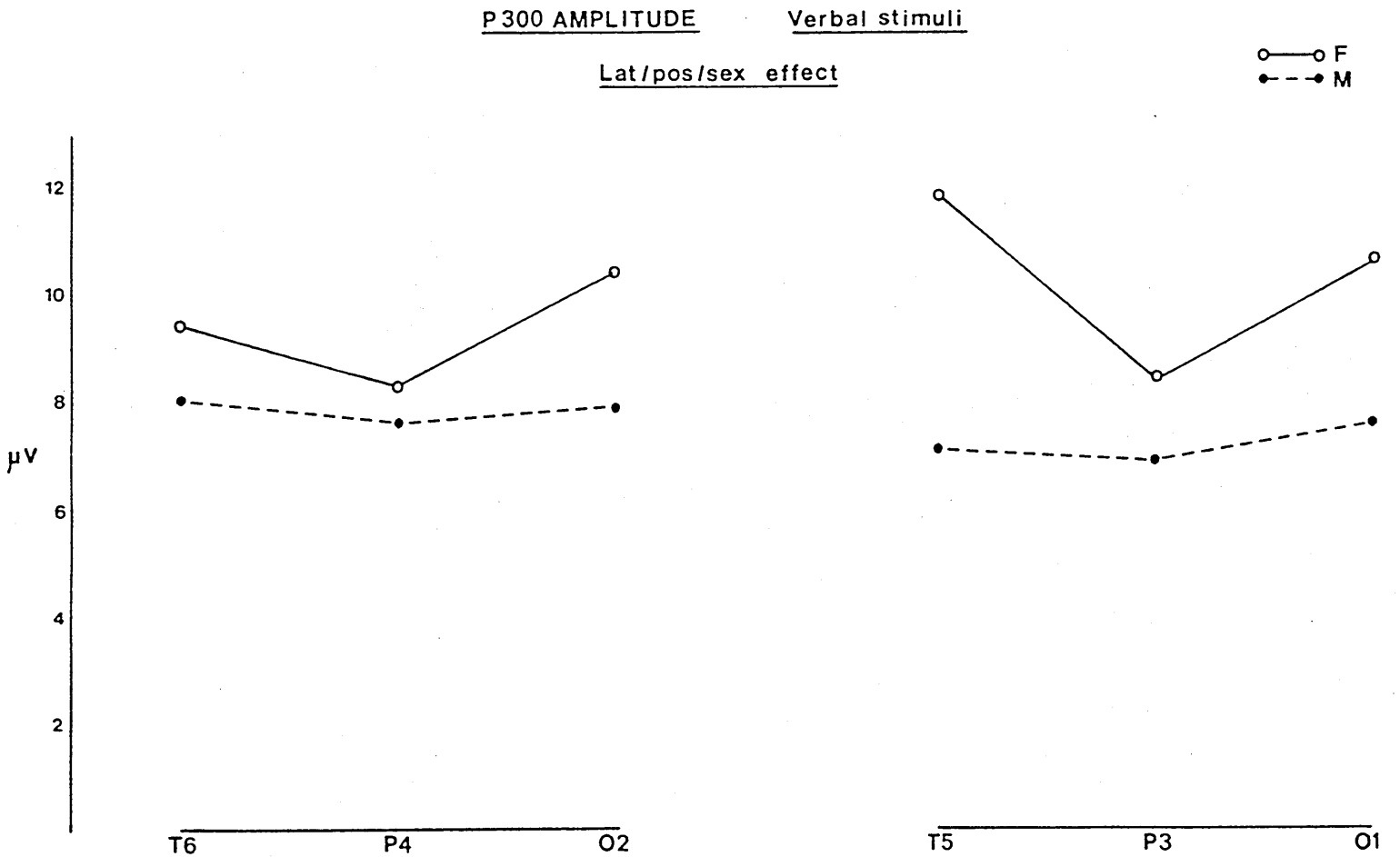


Fig 7:9 Amplitude (uV) of P300 at the six electrode positions for males (dotted line) and females (solid line) in response to slides of words.

P300 LATENCY

TABLE 7:10

ANOVA Table of probabilities for Verbal stimuli

Source	Degrees of freedom	F	Probabilities
Sex	1	1.57	0.2321
Error	13		
Laterality	1	1.37	0.2621
Laterality/Sex	1	0.94	0.3512
Error	13		
Position	2	0.74	0.4858
Position/Sex	2	0.01	0.9870
Error	26		
Laterality/Position	2	0.68	0.5176
Laterality/Pos/Sex	2	0.25	0.7782
Error	26		

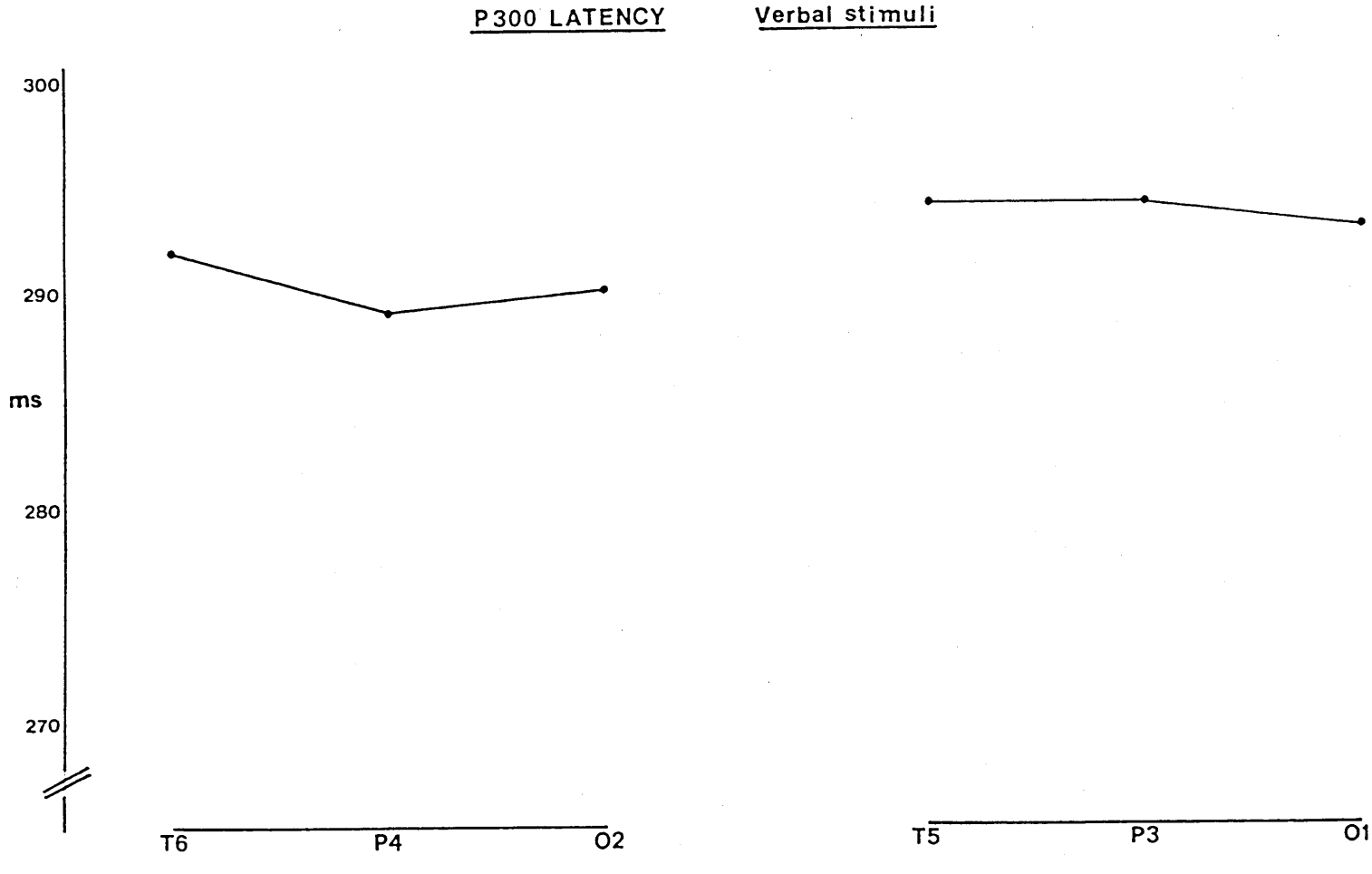


Fig 7:11 Latency (ms) of P300 at the six electrode positions in response to slides of words.

ANOVA: P100 latency

Table 7:5 and Fig 7:6 show the ANOVA results for P100 latency. Again, there were no significant effects.

ANOVA: P300 amplitude

Table 7:7 and Fig 7:8 present the ANOVA findings for P300 amplitude. There was no general effect of laterality. The only significant effect was an interaction between laterality, position and sex, $F(2,26) = 3.37$, $p < 0.05$ (just significant, $p = 0.0498$). Fig 7:9 shows the mean P300 amplitude for males and females separately at each electrode position. This component is generally of higher amplitude for females than males, but the significant interaction is due to P300 occurring in the left temporal region at 11.8 uV for female subjects compared to 7.1 uV for males, a difference of 4.7 uV.

ANOVA: P300 latency

Table 7:10 and Fig 7:11 give the ANOVA findings for P300 amplitude. There were no significant results.

Discussion

This experiment shows that both P100 and P300 can be evoked by viewing slides of words, when the only task is to watch the stimuli. With respect to P300 these results confirm the findings of Courchesne et al (1978), Friedman et al (1975) and Kutas and Hillyard (1982) who have reported the presence of a late wave in response to all categories of words.

P100 occurred in the range of 90 - 94 ms for latency and between 3.7 and 5.7 uV for amplitude. It is difficult to compare these values

with those of other workers because details of P100, in response to verbal stimuli, have rarely been reported. However, the present latency value of 90 - 94 ms is comparable to that of Courchesne, Courchesne and Hillyard (1978) who describe an early component between 90 and 150 ms in response to slides of single letters and digits. Friedman et al (1975) and Kutas and Hillyard (1982) report longer P100 latencies, at 140 and 120 - 150 ms respectively, in response to sequential words of a sentence.

When compared to the P100 values obtained with presentation (to the same subjects) of non-verbal material during Experiment 1, this component shows several differences. The overall P100 amplitude of 3.7 - 5.7 uV with verbal material is much smaller than that obtained with slides of faces (6.4 - 12.7 uV) and geometric designs (6.4 - 12.1 uV). However, it is comparable to the amplitude recorded from temporal and parietal regions with pattern reversal (4.9 - 6.4 uV) but the marked occipital maximum observed with pattern reversal and the other non-verbal conditions is not apparent. In fact the amplitude of P100 with word stimuli was very similar at all electrode sites and there was no significant position effect. This finding could either signify that slides of words proved insufficient in eliciting a response from the occipital region (perhaps due to factors related to luminance or contrast) or that verbal material is processed with less localisation.

P100 latency in response to verbal material (90 - 94 ms) is comparable to the values that were found with geometric designs and pattern reversal (89 - 96 ms) and similarly occurred approximately 24 ms earlier than that reported for known and unknown faces (114 - 118 ms).

Details of P300 in response to verbal stimuli have been described more frequently in the literature although absolute amplitude values have received little attention because the emphasis has usually been on

peak latencies. For P300 amplitude there was no significant general effect of laterality, a finding which is consistent with the lack of asymmetry reported by Shelburne (1972), Shelburne (1973) and Friedman et al (1975). The study by Squires (1983) may help to explain this negative finding. Recording the responses to auditory stimuli from depth and surface electrodes in chronic epileptics, he points out that even when marked E.P. asymmetries are present from cortical structures (i.e. limbic sites) the scalp potentials may be symmetrical. The present P300 mean latency value of 289 - 295 ms is similar to the lower end of the 300 - 600 ms range of the late wave described by Courchesne et al (1978) using single letters and digits, and by Friedman et al (1975) recording the response to individual words of a sentence. It is somewhat earlier than the 400 - 700 ms component reported by Kutas and Hillyard (1982). No previous study has compared the amplitude of P300 to verbal stimuli between males and females. There was no significant general effect of sex but there was an interaction between laterality, position and sex (Fig 7:9) caused by the amplitude of P300 being 4.7 uV larger for females, compared to males, in the left posterior-temporal region.

Considering the amplitude of P300 with respect to the values reported for non-verbal stimuli in Experiment 1, the overall range of 7.7 - 9.9 uV is much lower than that found with known and unknown faces (12 - 22 uV) and geometric designs (11 - 15 uV) but is similar to that described for pattern reversal (5.9 - 9.1 uV). Again, the topography differs from that seen in response to face stimuli which showed a clear maximum amplitude in temporal and occipital regions. In contrast, P300 amplitude to verbal stimuli was similar at all electrode sites; there was no significant general effect of position. If it is accepted that an area

of maximum amplitude reflects increased cortical processing then this result suggests that there is no one clearly localised area for verbal material because slides of words activate temporal, parietal and occipital regions equally.

Comparing P300 latency between verbal and non-verbal conditions the mean of 289 - 295 ms in response to word stimuli is similar to that found with known and unknown faces (289 - 293 ms) but is considerably later, by approximately 20 ms, than the 265 - 279 ms recorded with geometric designs and pattern reversal. These findings do not support the results of Buchsbaum and Fedio (1969) who describe a positive component which was 24 ms earlier for words compared to non-verbal stimuli. However, their positivity occurred between 190 and 280 ms, at a much shorter latency than the present P300, and therefore may not be strictly comparable.

It is interesting to note the difference of 200 ms between the mean latencies of P100 and P300 in response to word stimuli. Experiment 1, with non-verbal slides, had shown a consistent P100/P300 interval of 175 to 180 ms; for example: with both face conditions the mean P100 latency was 116 ms and P300, 292 ms, a difference of 176 ms. Similarly, with geometric designs and pattern reversal the mean P100 and P300 values were 92 ms and 270 ms respectively, a difference of 178 ms. This fairly uniform time interval seemed to suggest that the latency of P300 was dependent on that of P100. However, the latencies of these two components in response to verbal stimuli indicate otherwise because the mean P100 latency (92 ms) was similar to that found with designs and pattern reversal (92 ms) but was earlier than P100 with face conditions (116 ms). Conversely, P300 (with a mean latency of 292 ms in response to words) was later than that recorded with designs and pattern reversal (265-275 ms)

though similar to the latency with faces (292 ms). This finding clearly shows that the latency of P300 with verbal stimuli is independent of P100 and also prompts the question as to why this component should be so much later. Slides of words and those of faces have two factors in common which are not shared with pattern reversal and geometric designs: both have cognitive content and both show a 20 ms P300 delay. It seems likely, therefore, that this increase in latency represents additional cortical processing, substantiating the view that P300 is indeed related to cognition.

To summarise the main findings: P100 and P300 were elicited by slides of common words. Both components were of low amplitude and showed a different topography to that found previously with non-verbal conditions. There was no general asymmetry in P300 amplitude but females showed a larger response, compared to males, in the left temporal region. The latency of P300 was shown to be independent of P100 and in the same range as that recorded in response to faces, suggesting that this component does reflect cognitive processing.

The first four experiments have provided a considerable amount of information relating to the evoked potential waveform in normal subjects, including the range and variability of P100 and P300 with handedness, sex and age, and in response to six different types of visual stimuli. This collection of data is an essential prerequisite for any subsequent investigation of patients with cerebral dysfunction because confident predictions and comparisons can only be made with reference to the natural variability found in the normal population. The opportunity to study patients with interesting and related neuropsychological deficits

subsequently arose and the next two chapters deal exclusively with the changes in the evoked potential waveform associated with cerebral damage.

CHAPTER 8

EXPERIMENT 5

Investigation of a patient with prosopagnosia

Prosopagnosia, a very rare syndrome involving an inability to recognise a highly familiar person from facial cues alone, was described in considerable detail in Chapter 1 and the disagreement regarding the localisation of causative lesion(s) and whether or not the deficit occurs in isolation has also been discussed at some length. Without detracting from the controversial nature of these issues there can be no doubt that for a study concerned with face processing mechanisms a patient with prosopagnosia provides an ideal subject. R.B., a 53 year old plumber, was just such a case.

He presented in May, 1975 with sudden onset of feelings of unreality and difficulty in recognising familiar faces, followed by depression. Psychometry (Maida Vale Hospital) indicated a poor verbal memory and a profile suggestive of a right temporo-parietal lesion. CT scan at this time and on subsequent occasions (September 1975 (Fig 8:1a) and December 1976) revealed a low density, well defined area in the right posterior parietal region, without any evidence of progression. In the autumn of 1975 his visual problems became worse and this made his job very difficult because he was unable to use his tools appropriately and he had difficulty matching patterns. He sometimes failed to recognise his wife at a distance, had difficulty recognising television personalities, and tended to get lost in unfamiliar surroundings. His memory was

slightly impaired and he was clumsy at skilled motor activities such as dancing.

On admission to the Radcliffe Infirmary, Oxford in May, 1977 he was found to have a left upper homonymous quadrantanopia and an impaired ability to recognise the details of facial features. There was no dysphasia but some hesitation in reading and memorisation was poor. Neurological examination was otherwise normal. The E.E.G. showed bitemporal focal theta waves with a left anterior temporal emphasis. CT scan again revealed a persistent right temporo-parietal lesion and repeat scan in July, 1977 showed an additional low density area above the left lateral ventricle.

In June 1977 the patient underwent extensive psychological investigation by Dr. Freda Newcombe at the MRC Neuropsychology Unit, University Dept. of Clinical Neurology, Oxford, who noted that the prosopagnosia was not as severe as has been reported in other cases; he could recognise his family in a familiar context but might misidentify them at an unexpected meeting or in a crowd (Newcombe, 1979). He showed a moderate degree of topographical difficulty being unable to remember simple left and right turns but there was no apraxia or disturbance of body image. The patient reported other visual difficulties not limited to the recognition of faces; for example, although he could identify a category (flowers, race horses and cars) he could not identify a particular example.

On formal testing there was ample evidence of his difficulty on recognition tasks (using both unfamiliar faces and faces of famous people). He had difficulty at the level of sorting photographs into two groups, famous and unknown. The difficulty was not limited to recognition as it took him a long time to match photographs of different views of the same person and to pick out the photographs of a different face from two

identical photographs of another person. He rarely made errors in matching tasks but very long latencies reflected his search for distinguishing features such as the hairline or the shape of the mouth. His correct recognition scores with famous and unknown faces (compared to the mean scores of patients with right or left cerebral lesions and a group of controls) were as follows:

	Famous faces (t=20)	Unknown faces (t=12)
R.B.	13.0	7.0
Right posterior	17.3	8.2
Left posterior	17.9	10.0
Control	not available	10.5

His difficulties were not secondary to generalised intellectual deterioration nor were the visual difficulties due to a general derangement of visual spatial function for he obtained the maximum score on a visual cube counting test and performed well on a tactile task designed to study perceptual function in neurosurgical patients. The visual problems could not be ascribed to a gross sensory deficit either for acuity was adequate.

In an attempt to answer the interesting question as to whether the difficulty with faces was specific or whether faces were just an example of a complex type of visual stimuli that the patient found difficult to identify and remember, Dr Newcombe noted that there seemed to be a comparable difficulty with flowers and cars. In other words the category was easily recognised but the exemplar could not be distinguished.

The possibility of a selective memory impairment was also examined. Dr. Newcombe found the patient did not have a global amnesia (cf. his

performance on visual recognition and tactual maze learning tasks) but his performance on verbal memory tests was initially significantly impaired but improved as his depression lifted.

No obvious change was observed at neurological out-patient examinations in November 1977 and December 1978. CT scan, repeated in January 1980 (Fig 8:1b) showed bilateral deep parietal lesions, the area in the left hemisphere being larger than the right. The cause of these low density regions remained uncertain.

In September 1982, this patient kindly agreed to attend the Radcliffe Infirmary for additional testing. He was examined by Dr. D. Perrett (of the Psychology Laboratory, University of St Andrews, Fife) who investigated the patient's recognition of objects and famous faces presented lateralised to each half field. With object recognition (line drawings presented on video) performance was poor even with 1 second exposures, his correct recognition scores being 17% LVF and 7% RVF. With recognition of photographs of famous faces he correctly scored 0% LVF and 20% RVF. These results suggest that the patient's capacity to recognise faces depended predominantly on left hemisphere function, in contrast to the lateralised testing of object recognition where his performance was more accurate with LVF presentation, (i.e. a right hemisphere superiority).

The opportunity was taken to include this rare patient in the present thesis in order to observe his evoked potentials in response to slides of faces and control stimuli. It was expected that his left upper homonymous quadrantanopia might contribute to a distorted or delayed

Fig 8:1a CT scan September 1975

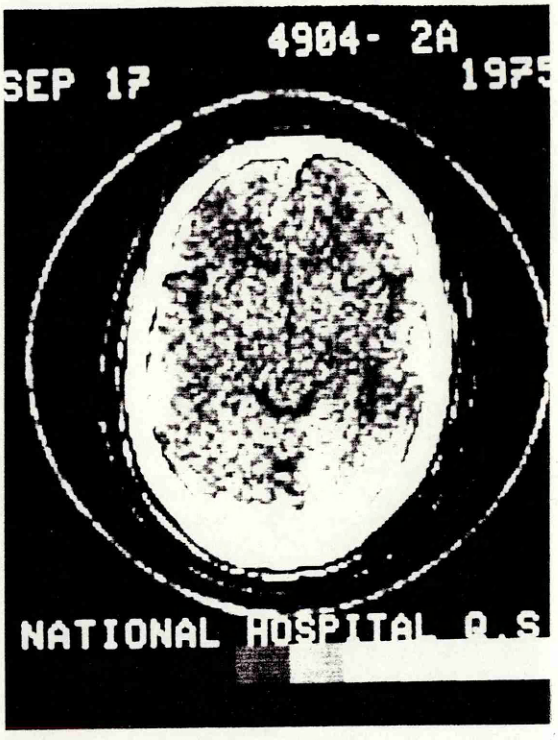
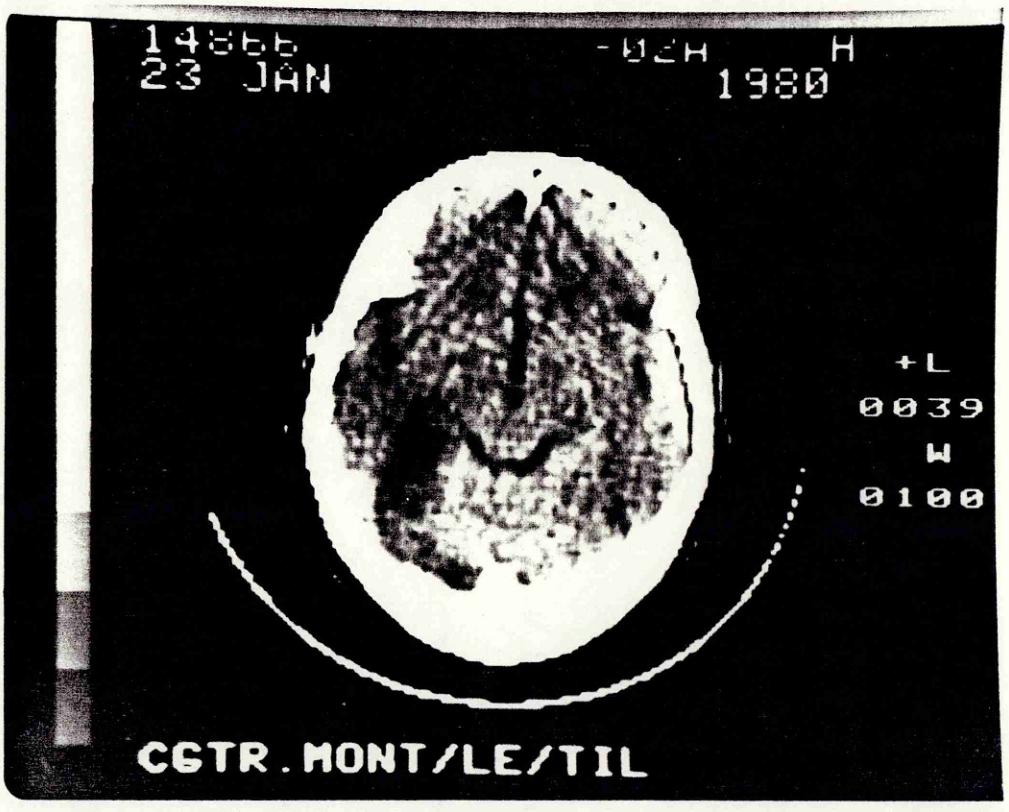


Fig 8:1b CT scan January 1980



P100. Because of the complicated nature of R.B.'s condition, i.e. Dr. Newcombe's findings of an impairment in the recognition of both familiar and unfamiliar faces, the patient's self report of difficulty with patterns and the bilateral CT scan lesions, it was difficult to form a confident prediction regarding P300, but it was thought likely that this potential (compared to control data) might be reduced or significantly delayed over the right hemisphere (particularly in temporal or parietal regions) when recorded in response to both known and unknown faces and geometric designs.

Brief procedure

The patient's visual acuity at the time of testing was right eye 6/6 and left, 6/9. He viewed four types of stimuli: pattern reversal, geometric designs, upright known and unknown faces, during a single session. Forty-two sweeps were averaged for known faces and 64 sweeps for the other three conditions.

Recordings were made from electrodes placed over the right and left posterior temporal, parietal and occipital regions referred to Fz. Two electrodes were also applied above and below the left eye (above the eye = amplifier grid 1) in order to record eye movement potentials. After the recording session all the known slides were presented again to the patient on a small slide viewer and he was requested to try and name each one. If he could not, he was asked to state if he recognised the face at all (and to give some clue to identification) or otherwise to say if he had no idea who it was. His score, together with the normal controls' mean and range values, are shown in the following table:

	Named correctly	Recognised (but not named)	Not recognised at all or misnamed
Patient R.B.	16	18	8
Control Mean	34	5	3
Poorest control	19	12	11
Best control	40	0	2

(Known faces n = 42)

Results

Evoked responses were recorded at all electrode sites for the four conditions. Table 8:2 and 8:3 give the mean latencies and amplitudes for P100 and P300 respectively, at each electrode and for the four types of stimuli.

The patient's P100 and P300 amplitudes and latencies were compared with respective P100 and P300 values of the male, right handed controls computed in Experiment 1. (This normal group consisted of 15 men, mean age 32 years, range 22 to 61 years). An ANOVA effect was defined as the difference between the means of the control group and that of the patient's values. This type of comparison was performed separately on each of the four dependent variables, namely P100 amplitude, P100 latency, P300 amplitude and P300 latency.

ANOVA: P100 amplitude

Table 8:4 and Fig 8:5 present the ANOVA results for P100 amplitude, $p < 0.05$ again being regarded as significant in respect to the table of probabilities. No significant P100 amplitude difference was found between comparison of the patient and the control group means.

R.B. PROSOPAGNOSIC PATIENT

KNOWN AND UNKNOWN FACES

GEOMETRIC DESIGNS AND PATTERN REVERSAL

P100 AMPLITUDES AND LATENCIES

TABLE 8:2

		T6	P4	O2	T5	P3	O1
KNOWN FACES	lat (msec)	137.9	152.7	152.7	152.7	152.7	152.7
	amp (uV)	5.3	5.0	6.8	4.7	5.8	9.2
UNKNOWN FACES	lat	123.1	133.0	123.1	123.1	123.1	123.1
	amp	6.6	5.5	7.8	5.8	6.9	8.1
GEOMETRIC DESIGNS	lat	133.0	142.8	142.8	133.0	133.0	133.0
	amp	4.9	4.8	6.3	4.9	5.5	6.0
PATTERN REVERSAL	lat	164.2	149.2	149.2	134.3	124.3	124.3
	amp	3.9	3.5	3.2	2.7	2.0	3.2

R.B. PROSOPAGNOSIC PATIENT

KNOWN AND UNKNOWN FACES

GEOMETRIC DESIGNS AND PATTERN REVERSAL

P300 AMPLITUDES AND LATENCIES

TABLE 8:3

		T6	P4	O2	T5	P3	O1
KNOWN FACES	lat (msec)	345.0	345.0	345.0	345.0	345.0	345.0
	amp (uV)	12.4	8.7	13.9	11.0	9.5	12.6
UNKNOWN FACES	lat	297.0	297.0	297.0	297.0	297.0	297.0
	amp	11.6	5.8	12.7	12.5	9.0	13.0
GEOMETRIC DESIGNS	lat	295.6	295.6	295.6	295.6	290.6	290.6
	amp	11.2	10.1	11.5	8.8	6.8	10.7
PATTERN REVERSAL	lat	254.0	254.0	254.0	229.0	219.0	219.0
	amp	3.5	3.9	2.7	3.2	2.9	2.9

P100 AMPLITUDE TABLE 8:4

ANOVA Table of probabilities. Prosopagnosic patient

Known and unknown faces, geometric designs and pattern reversal

Source	Degrees of freedom	F	Probabilities
Patient effect	1	0.99	0.3371
Error	14		
Condition/Pt effect	3	0.08	0.9720
Error	42		
Lat/Pt effect	1	0.36	0.5554
Error	14		
Cond/Lat/Pt effect	3	0.08	0.9730
Error	42		
Position/Pt effect	2	1.42	0.2590
Error	28		
Cond/Pos/Pt effect	6	0.28	0.9471
Error	84		
Lat/Pos/Pt effect	2	0.58	0.5686
Error	28		
Cond/Lat/Pos/Pt effect	6	0.20	0.9761
Error	84		

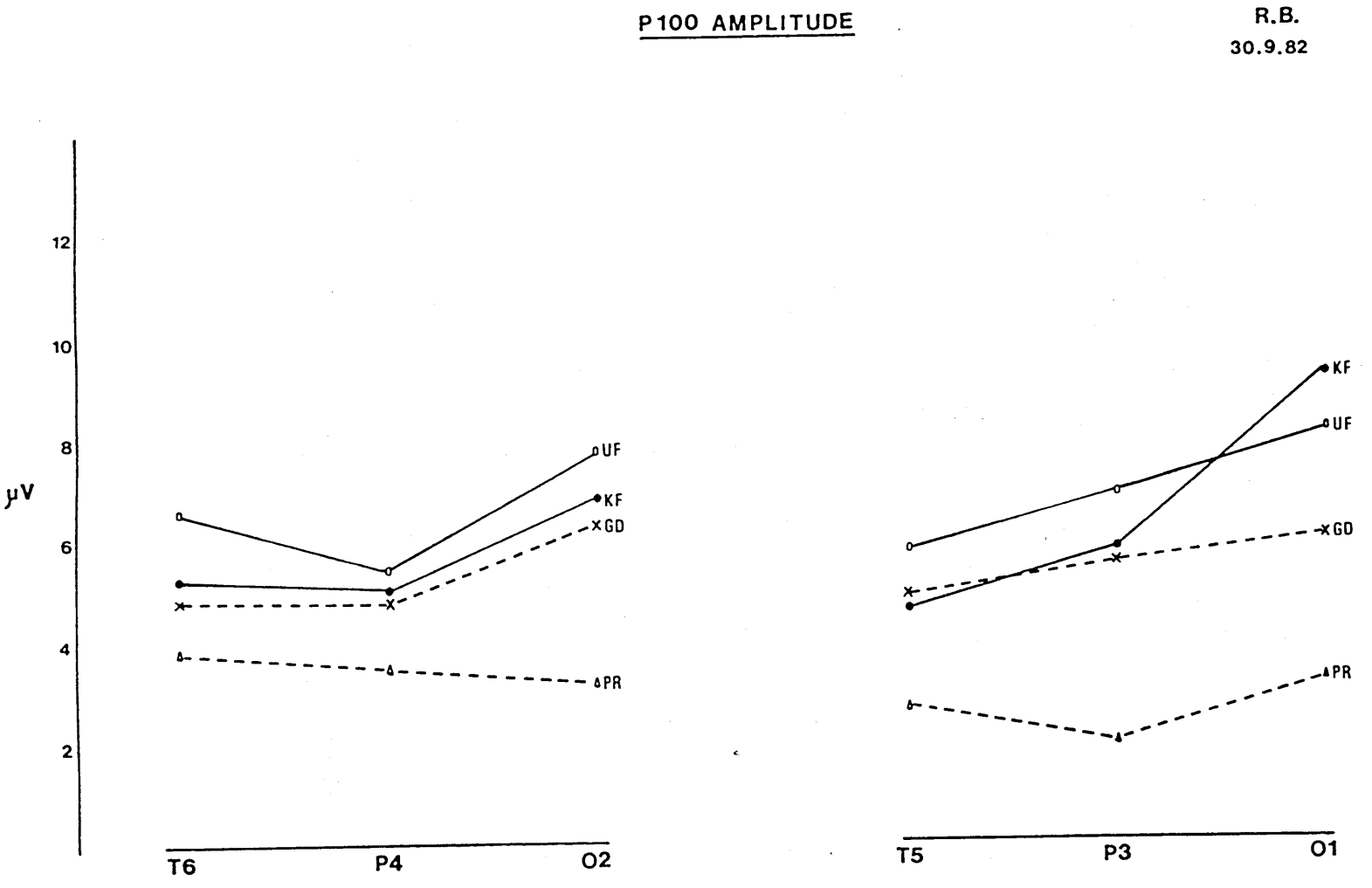


Fig 8:5 Amplitude (uV) of P100 at the six electrode positions for the four stimulus conditions.

ANOVA: P100 latency

Table 8:6 and Fig 8:7 show the ANOVA results for P100 latency. There was a significant general P100 latency effect between the patient and the control group, $F(1,14) = 12.71$, $p < 0.01$. The control group's overall P100 latency (averaged irrespective of condition, hemisphere and electrode position) was 108.3 ms and for the patient, 138.0 ms. The patient's P100 latency was therefore generally 30 ms slower than the mean normal male value. As there was no interaction with condition, $F(3,42) = 1.79$, $p < 0.05$, this delay appeared equally in response to all four types of stimuli.

There was a difference between the control and the patient's P100 latency lateralisation $F(1,14) = 8.52$, $p < 0.05$. For right and left hemispheres the patient's P100 latency values were 141.9 ms and 134.1 ms respectively. In the patient, therefore, the right hemisphere responded approximately 8 ms slower than the left side.

The patient's laterality X condition mean latencies were also significantly different from the control means, $F(3,42) = 7.27$, $p < 0.001$. As there was no significant interaction with laterality X condition X position for either the control group or the patient, Table 8:8 and Fig 8:9 show right and left sided P100 latencies under the four conditions (irrespective of position) for normals and the patient. The control group show symmetrical latencies for unknown face stimuli and geometric designs but a 3 ms difference (right hemisphere slower than left) which was equal at the three electrode sites, with both known faces and pattern reversal. The patient's P100 latencies however are slower on the right side for unknown faces (3 ms), geometric designs (6.5 ms) and pattern reversal (27 ms) but slower on the left side by 5 ms for known faces. With reference to Table 8:2 it appears that for the patient these

P100 LATENCY Table 8:6

ANOVA Table of probabilities Prosopagnosic patient

Known and unknown faces, geometric designs and pattern reversal

Source	Degrees of freedom	F	Probabilities
Patient effect	1	12.71	0.0031 *
Error	14		
Condition/Pt effect	3	1.79	0.1634
Error	42		
Lat/Pt effect	1	8.52	0.0112 *
Error	14		
Cond/Lat/Pt effect	3	7.72	0.0005 *
Error	42		
Position/Pt effect	2	0.35	0.7055
Error	28		
Cond/Pos/Pt effect	6	2.25	0.0463 *
Error	84		
Lat/Pos/Pt effect	2	1.87	0.1725
Error	28		
Cond/Lat/Pos/Pt effect	6	0.63	0.7037
Error	84		

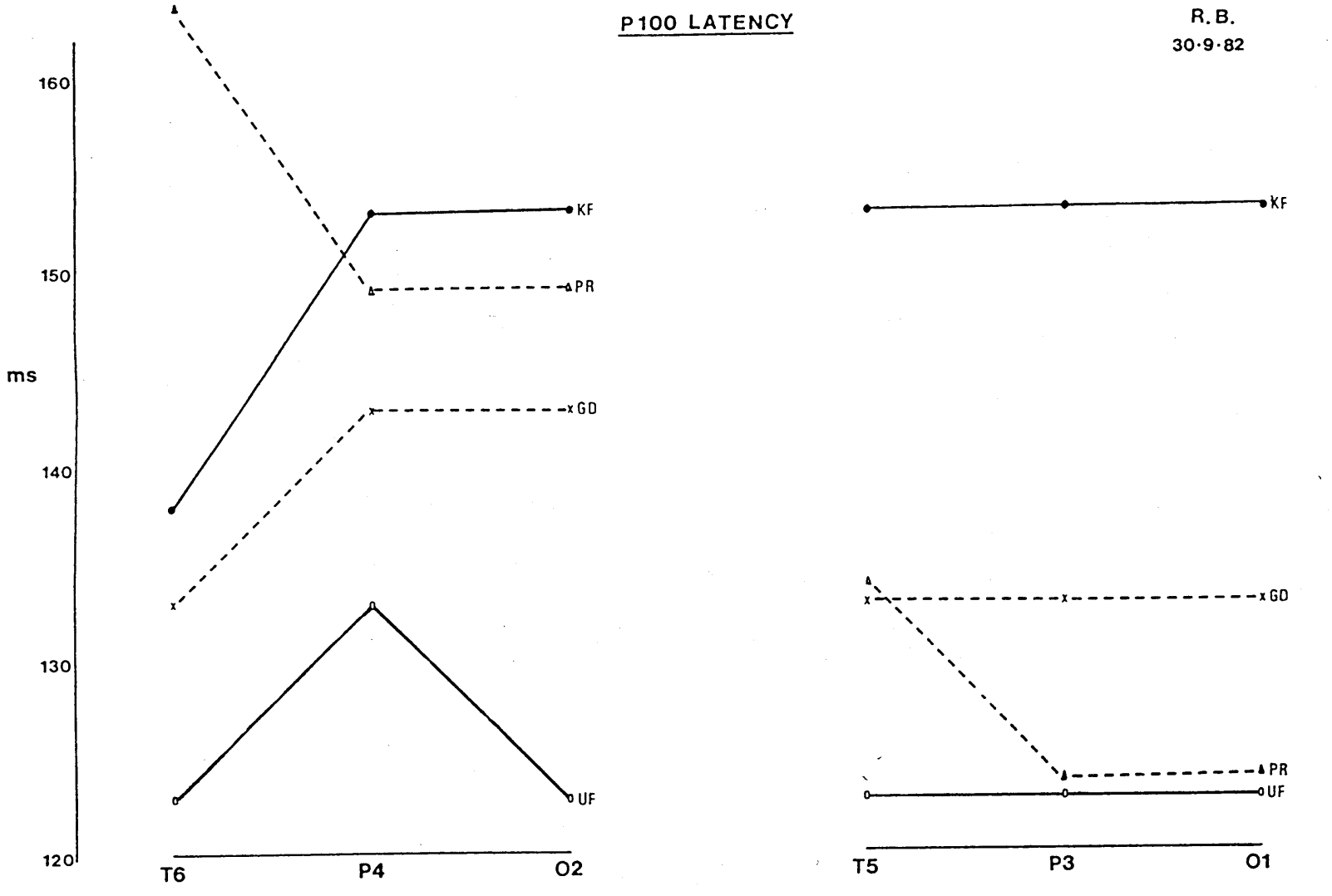


Fig 8:7 Latency (ms) of P100 at the six electrode positions for the four stimulus conditions.

P100 LATENCY

PATIENT RB COMPARED WITH MALE CONTROL GROUP

LATERALITY X CONDITION EFFECT

	Male control group		Patient	
	Right	Left	Right	Left
KNOWN FACES	122.6 ms	119.1	147.8	152.7
UNKNOWN FACES	124.3	124.9	126.4	123.1
GEOMETRIC DESIGNS	95.3	95.2	139.5	133.0
PATTERN REVERSAL	95.1	92.1	154.2	127.6

Table 8:8 Latency of P100 over the right and left hemispheres of the patient and the control group, under the four stimulus conditions.

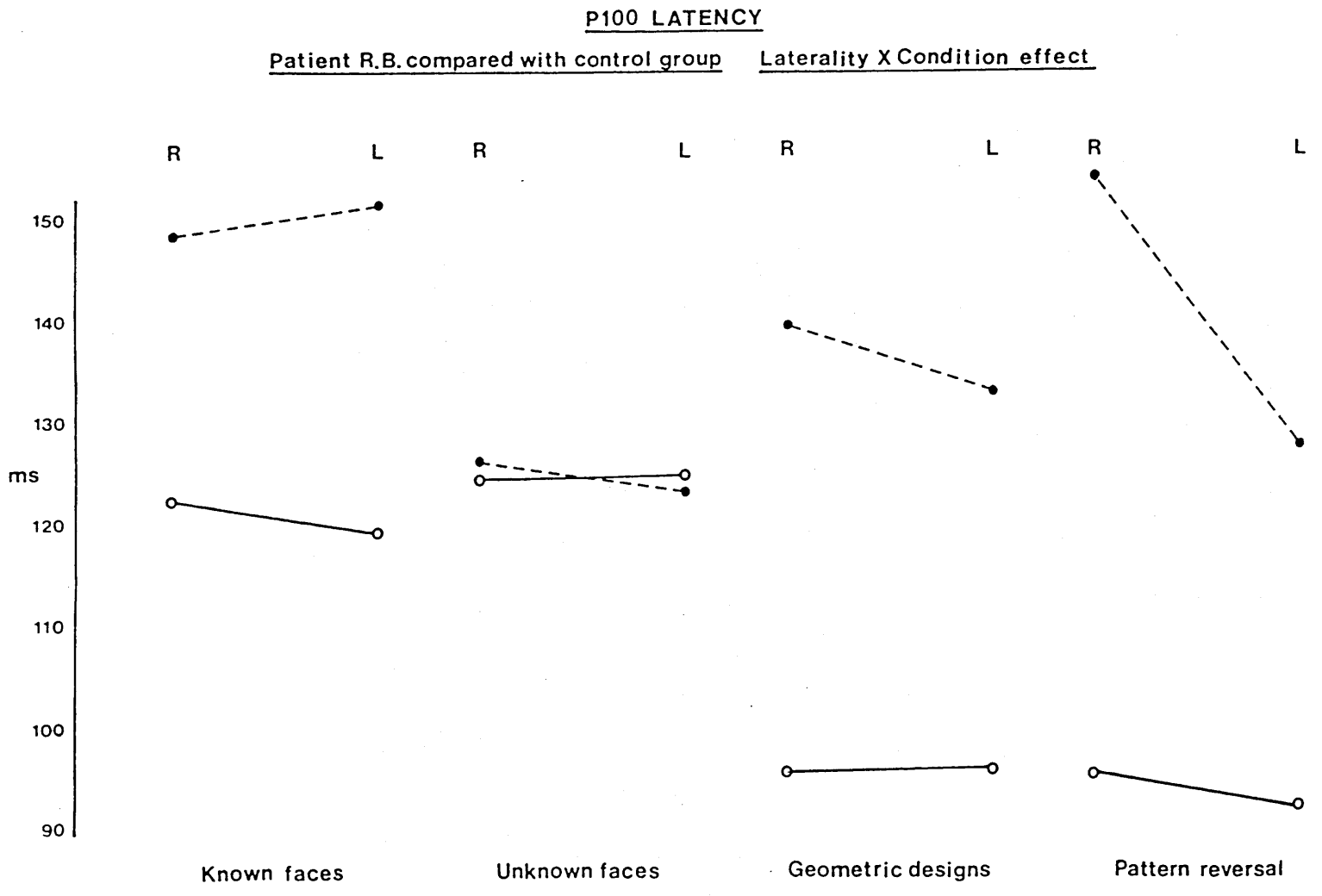


Fig 8:9 Latency (ms) of P100 over the right and left hemispheres of the patient (dotted lines) and the control group (solid lines) under the four stimulus conditions.

lateralised latency differences are not equal at the three electrode positions except with pattern reversal (when the right side is consistently slower than the left by 25 to 30 ms) and geometric designs (with the exclusion of the temporal region). With unknown faces the right sided P100 is slower only in the right parietal area and for known faces P100 from the left hemisphere is slower only in the temporal region.

A condition X position interaction proved just significant for the the patient versus the control group comparison, $F(6,84) = 2.25$, $p < 0.05$. Table 8:10 shows P100 latency values at each site (temporal, parietal and occipital, irrespective of hemisphere) under the four conditions for the control group and the patient. The controls show little topographical difference in latency during the four conditions. However, the patient's P100 latency differences between electrodes are quite variable across conditions. Comparison between the three intra-subject electrode positions show that P100 occurs (i) with known faces 7 ms earlier temporally, (ii) with unknown faces 5 ms earlier temporally and occipitally, (iii) with geometric designs 5 ms earlier temporally and (iv) with pattern reversal 12.5 ms earlier parietally and occipitally. There were no other significant interactions.

ANOVA: P300 amplitude

Table 8:11 and Fig 8:12 show the results for P300 amplitude. There were no significant differences whatsoever in comparisons between the means of the patient and the control group.

ANOVA: P300 latency

Table 8:13 and Fig 8:14 give the ANOVA results for P300 latency. Again, there were no significant interactions between the patient and the control group means. Although Table 8:3 indicates a considerably later

P100 LATENCY

PATIENT RB COMPARED WITH MALE CONTROL GROUP

CONDITION X POSITION EFFECT

	Male control group			Patient		
	Temporal	Parietal	Occipital	Temporal	Parietal	Occipital
KNOWN FACES	120.9 ms	120.9	120.7	145.3	152.7	152.7
UNKNOWN FACES	124.5	124.4	124.9	123.1	128.0	123.1
GEOMETRIC DESIGNS	95.4	94.9	95.6	133.0	137.9	137.9
PATTERN REVERSAL	95.2	92.9	92.7	149.2	136.7	136.7

Table 8:10 Latency of P100 at the three recording sites (irrespective of hemisphere) under the four stimulus conditions, for the patient and the control group.

P300 AMPLITUDE TABLE 8:11

ANOVA Table of probabilities Prosopagnosic patient

Known and unknown faces, geometric designs and pattern reversal

Source	Degrees of freedom	F	Probabilities
Patient effect	1	0.79	0.3944
Error	11		
Cond/Pt effect	3	0.09	0.9648
Error	33		
Lat/Pt effect	1	0.22	0.6502
Error	11		
Cond/Lat/Pt effect	3	1.45	0.2461
Error	33		
Position/pt effect	2	0.02	0.9755
Error	22		
Cond/Pos/Pt effect	6	0.33	0.9201
Error	66		
Lat/Pos/Pt effect	2	0.06	0.9388
Error	22		
Cond/Lat/Pos/Pt effect	6	0.52	0.7887
Error	66		

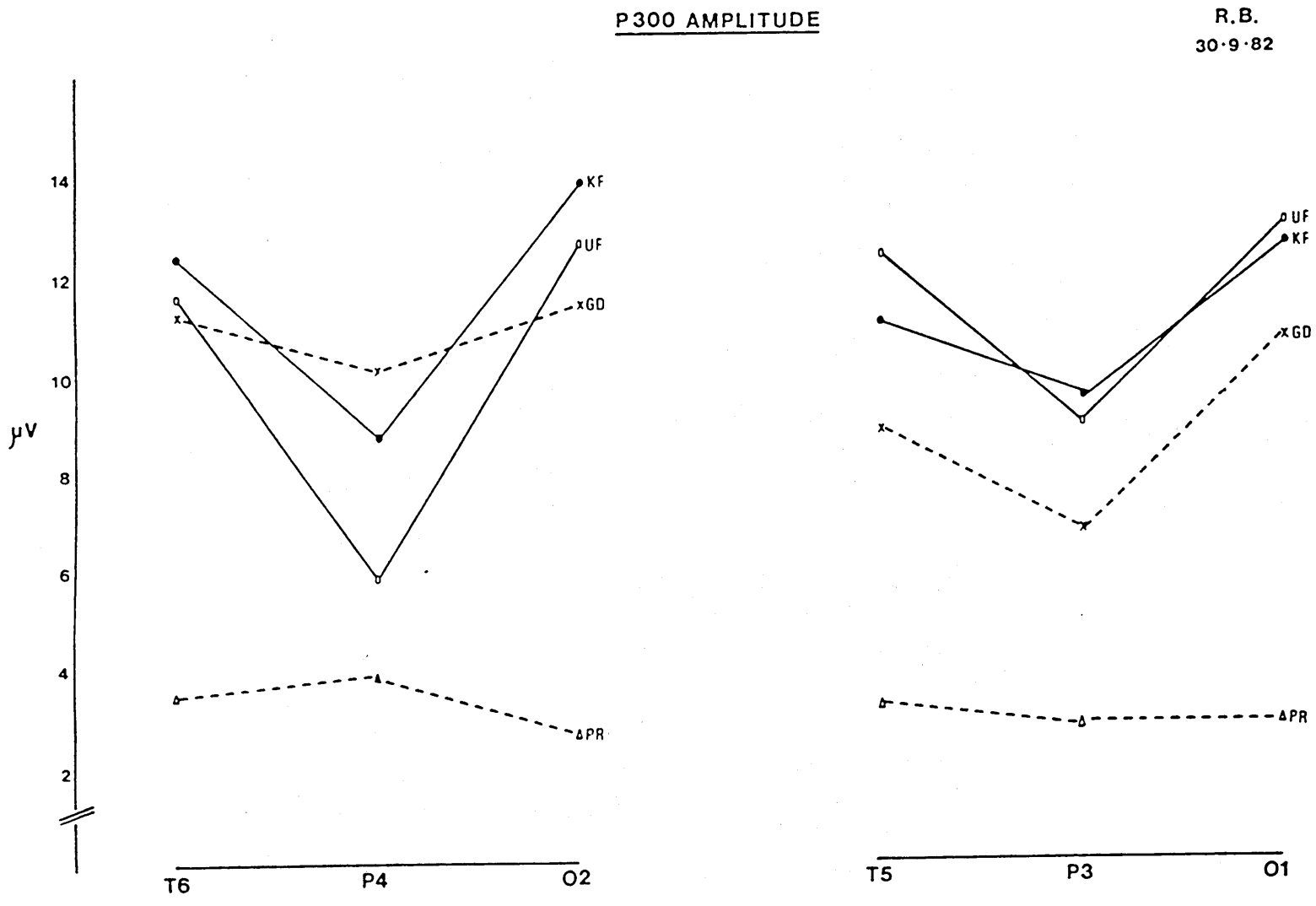


Fig 8:12 Amplitude (uV) of P300 at the six electrode positions under the four stimulus conditions.

P300 LATENCY TABLE 8:13

ANOVA Table of probabilities Prosopagnosic patient

Known and unknown faces, geometric designs and pattern reversal

Source	Degrees of freedom	F	Probabilities
Patient effect	1	0.00	0.9584
Error	11		
Cond/Pt effect	3	1.30	0.2896
Error	33		
Lat/Pt effect	1	0.64	0.4418
Error	11		
Cond/Lat/Pt effect	3	0.99	0.4101
Error	33		
Position/Pt effect	2	0.45	0.6458
Error	22		
Cond/Pos/Pt effect	6	0.16	0.9868
Error	66		
Lat/Pos/Pt effect	2	0.06	0.9415
Error	22		
Cond/Lat/Pos/Pt effect	6	0.05	0.9994
Error	66		

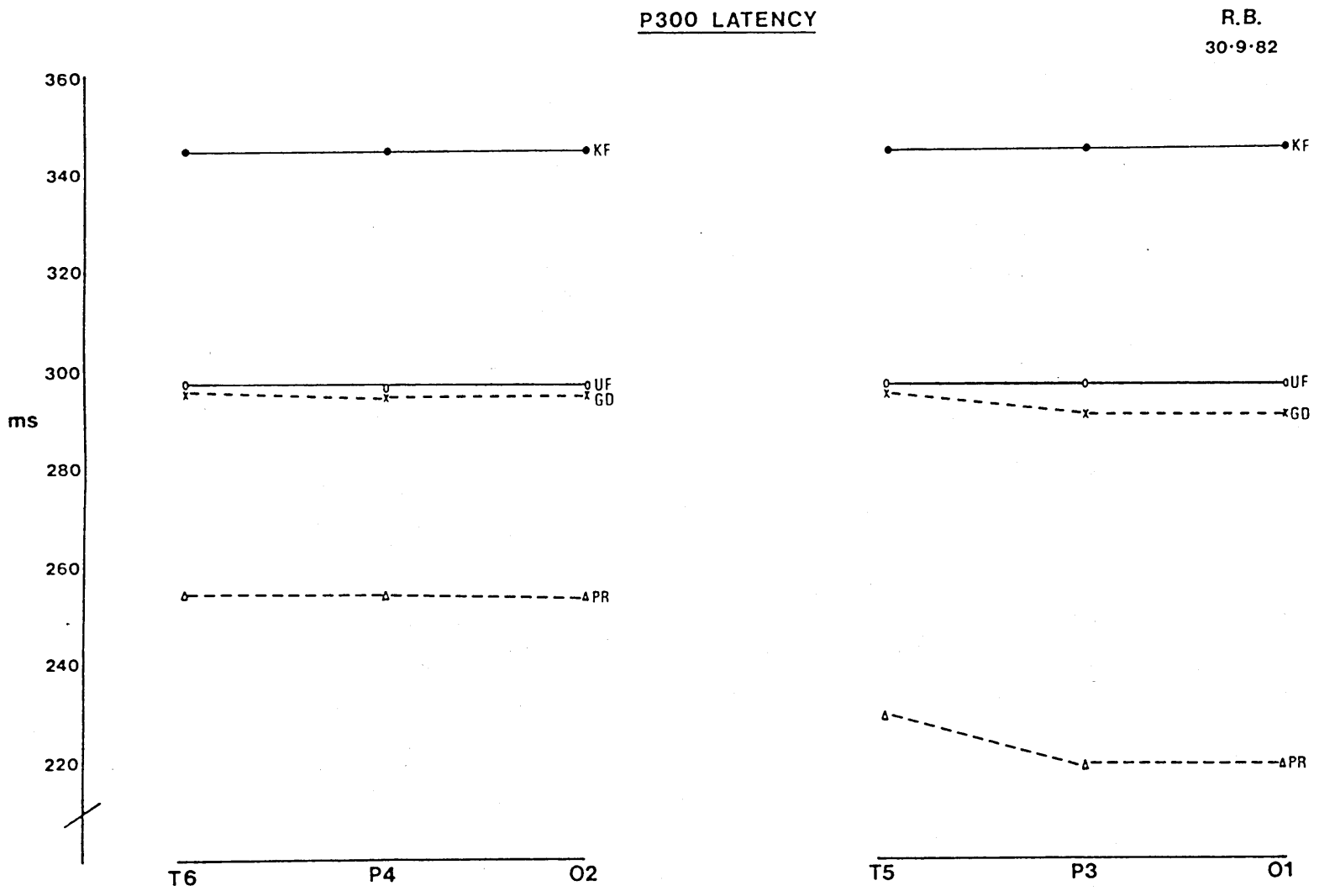


Fig 8:14 Latency (ms) of P300 at the six electrode positions under the four stimulus conditions.

P300 with known faces (345.0 ms) than with the other three conditions, this did not prove significant and inspection of the control raw scores with this type of stimuli in fact shows two normal subjects with P300 latencies also in the range of 340 to 350 ms.

Discussion of results.

Statistical comparisons between the patient and the male control group show that there were no significant differences at all for P100 amplitude, P300 amplitude or P300 latency. Therefore, for these three variables, the prosopagnosic patient fell within normal limits for male subjects.

In contrast, the comparison for P100 latency shows several significant differences. The latency of this component in the patient was generally 30 ms slower compared to the mean of the control group and as there was no significant interaction with the type of condition this delay appeared equally during all four types of stimuli. This initial finding, of a P100 latency delay from both hemispheres during all conditions, strongly suggests a bilateral cortical disturbance in the processing of a visual stimulus at its early, sensory level. Although the exact origins of P100 remain obscure, reference to the known functional localisation of line and face perception in man (Fried et al, 1982) suggests that P100, in this patient, is delayed along the pathways to the primary visual cortex and the region of the parieto-occipital junction.

This general latency effect interacted with lateralisation. Although in the normal male group there was a 1.5 ms hemisphere difference in latency, (the right side responding more slowly than the left) the patient showed this more markedly, his right hemisphere

responding 8 ms later than the left. Compared to the normal males he therefore showed an overall 6.5 ms latency delay from the right hemisphere. Although the patient's visual acuity was in the normal range (R:6/6, L:6/9) this finding of a delayed right hemisphere P100 response, by itself, could perhaps have been explained in terms of his left upper homonymous quadrantanopia, assuming that he did fixate centrally during all conditions. However, if the delay was due entirely to such a deficit, the latency difference between the hemispheres should have occurred consistently with all four conditions, yet this was not the case. The patient showed a highly significant interaction betweeen the lateralisation effect and the type of condition with a general right sided delay occurring in response to geometric designs and very markedly with pattern reversal. Because the patient versus the control lateralisation X condition X position interaction proved non-significant there was no evidence to indicate that the discrepancies found with known and unknown face stimuli were meaningful. The patient's lateralisation X condition effect therefore seems to be caused by a fairly generalised right sided delay during geometric designs and pattern reversal.

This finding, of a particularly prolonged right sided latency with geometric designs and pattern reversal, is consistent with evidence from other studies that the right posterior region is more involved than the left in pattern and shape recognition (De Renzi and Spinnler, 1966; Warrington and Rabin, 1970) and might offer an explanation for the patient's own reported difficulties in matching textured patterns. The fact that this delay showed no interhemispheric differences with known or unknown faces (but was present with geometric designs and pattern reversal) is quite unexpected and the variability between conditions rules out the left upper quadrantanopia as the sole contributing factor. This

dissociation of P100 latency between the conditions (in an entirely different manner to that observed in normal controls) does infer that some type of stimulus specific organisation occurs even at an early sensory level. Fried et al (1982), using the technique of electrical stimulation mapping to determine intrahemispheric visiospatial functions in awake humans, have found that perception for such material is altered in the region of the parieto-occipital junction, providing evidence for discrete functional localisation within the right hemisphere. However, they also report that at the sites of stimulation which altered perception, upright unfamiliar faces and line orientation were equally vulnerable. In other words, there was no dissociation in the cerebral localisation of perception for upright faces and line orientation. Such evidence of a common functional region certainly suggests that P100 should indeed have been similarly affected with faces and geometric shapes in this patient. (It must be pointed out that Fried et al recorded exclusively from the right, non-dominant cortex because obvious limitations of the technique prevented simultaneous, bilateral investigation. The contribution of the left hemisphere to face perception was therefore not observed).

Whilst the control group showed no differences in P100 latency across electrode position according to the type of stimuli except possibly with pattern reversal (when the response appeared earlier in parietal and occipital regions), the patient showed just significant topographical differences compared to the normal group. His earlier response in parietal and occipital regions (compared to the temporal area) with pattern reversal exaggerates the trend found in the control group. With known faces, unknown faces and geometric designs his

responses tended to occur earlier in temporal areas indicating a delay (5 to 7 ms) in parietal and occipital regions. Because this effect of electrode position did not interact with lateralisation and type of condition this result suggests bilateral cerebral disturbance maximal parieto-occipitally.

It is of interest that while P100 was prolonged there was no significant corresponding delay in P300. Although R.B.'s P300 latency values initially seemed late previous results from normal volunteers (Experiments 1 and 2) clearly indicate that the latency of this component occurs with a wide intersubject variability and inspection of P300 values from the normal men used in the ANOVA comparisons reveals two controls with the same range as the patient. It appears that a wide P300 latency variability can obscure a 30 ms P100 delay. This leads to another noteworthy point. Experiment 1, with normal controls, using exactly the same types of stimuli, indicated that a consistent interval occurs between P100 and P300. R.B.'s P100 latency, but not P300's, was significantly different from the controls, suggesting that in this patient the timing between these two components varies from the normal mean (though the picture is complicated by his considerable variability caused by the type of condition and electrode position). This finding strengthens the results of Experiment 4 in which P300 was found to be independent of P100 with verbal material.

One other explanation for this, which can only tentatively be put forward due to the unknown origins of late evoked potential components, is that the visual association areas (the presumed generating sites for P300) receive a direct connection from the optic pathway prior to the primary visual cortex. P300 would then occur at the correct latency despite a prolonged P100. The biological significance for such circuitry

remains unclear but possible evidence for such a pathway has been described by Spehlmann et al (1977). Present but simplified V.E.P.s were recorded in a cortically blind patient subsequently shown to have extensive, bilateral infarction of occipital white matter and cortex, suggesting an extrageniculocalcarine pathway to secondary visual cortex.

The relevance of these findings must be critically examined. Although cerebral localisation and corresponding function have been well documented, respective correlation with the evoked potential waveform has not been firmly established because of the limitations associated with human intracranial investigation. While the present experiment was undertaken in order to examine the relationship between waveform and function it must be emphasised that the results pertain to one patient only, an unavoidable situation due to the rarity of prosopagnosia. Only when other patients with this disorder have been examined electrophysiologically, and such results compared with those found in patients with more generalised visual memory disturbance, will it be possible to establish the type of E.P. variation that is specific to facial memory.

In summary, the evoked potential investigation of this 53 year old patient showed no differences in P100 amplitude, P300 amplitude or P300 latency when compared to the normal male group. The expectation of a variation in P300 amplitude to face stimuli was not confirmed; there were no significant E.P. differences between the patient and controls specifically related to the face conditions. This result may reflect the fact that, as noted in the 1977 neuropsychological report, the patient did not have pure or even severe prosopagnosia. There was however a significant delay in the latency of P100 from both hemispheres, indicative of a bilateral cortical disturbance, in keeping with the

results of the CT scan. This prolonged latency was asymmetrical, showing a right sided emphasis with geometric designs and pattern reversal, a finding consistent with other studies which have provided evidence supportive of the right hemisphere's role in pattern and shape recognition. This finding, of a dissociation in the interhemispheric delay, does raise the possibility of stimulus specific organisation at an early perceptual level.

CHAPTER 9

EXPERIMENT 6

The evoked responses in patients with missile injuries of the brain

The study of the single case, described in the previous chapter, proved informative and add to the growing body of evidence on selective, early visual processing (Livingstone and Habel, 1983). However, investigation of a larger number of subjects with brain dysfunction is obviously desirable although neurological patients can present major difficulties in lesion localisation because of infiltration and progression of disease. An ideal group would consist of patients with focal trauma and the opportunity subsequently arose to study a sample of men who had incurred missile injury to the brain during World War II. To explore the long term effects of these brain injuries a large number of ex-servicemen, under the supervision of Professor W.B. Matthews and Dr F. Newcombe, were invited to attend the MRC Neuropsychology Unit, University Department of Clinical Neurology, Oxford for intensive neurological and psychological review. Many of these patients had been similarly examined on several occasions since 1945. They came from all over Great Britain and their cooperation was entirely voluntary. Each man participated in a five day period of assessment, involving neurological examination, CT scan, visual field mapping and a battery of neuropsychological tests. If time allowed they were also requested to participate in the present study; there were no refusals from those who were asked.

This population of patients may be considered appropriate for the investigation of selective deficits for a number of reasons. The lesions

caused by high velocity missiles are focal and occur in healthy, adult brains usually with remarkably specific neurological and psychological sequelae (Russell and Espir 1961; Russell and Young, 1969). Furthermore, there is no convincing evidence that missile injury results in generalised intellectual deterioration (Jarvie 1960; Newcombe 1974) and the interpretation of deficits is not obscured by the progressive changes associated with tumour or cerebrovascular disease.

The aim of the experiment, therefore, was to establish how localised cortical lesions might affect the P100 and P300 components of the evoked potential under different stimulus conditions (faces, words and control stimuli) and to study the association between any alteration in waveform and the side and site of the lesion.

Brief Procedure

Twenty-four patients, all males, were studied. Their ages ranged from 58 to 71 years, mean age 64 years. Twenty-three patients were right handed and one, left; the right eye was dominant in 21, the left in 3. Visual acuity was 6/12 or better with each eye in all patients except in four whose scores were as follows: AH 6/24 in each eye, CT 6/24 in the right eye, AM 6/60 in the left eye and RT 6/60 in the right eye. Visual fields of each patient are shown Fig 9:1.

The patients were classified according to (i) the injured hemisphere and (ii) the locus of lesion of which there were five categories as follows: temporal, parietal, occipital, parieto-occipital and parieto-temporal. The exact site of each patient's missile wound had been charted on a brain map by a neurologist or neurosurgeon at the Head Injuries Centre shortly after injury. This method of charting was used and found reasonably accurate when compared to postmortem data by Russell and Espir

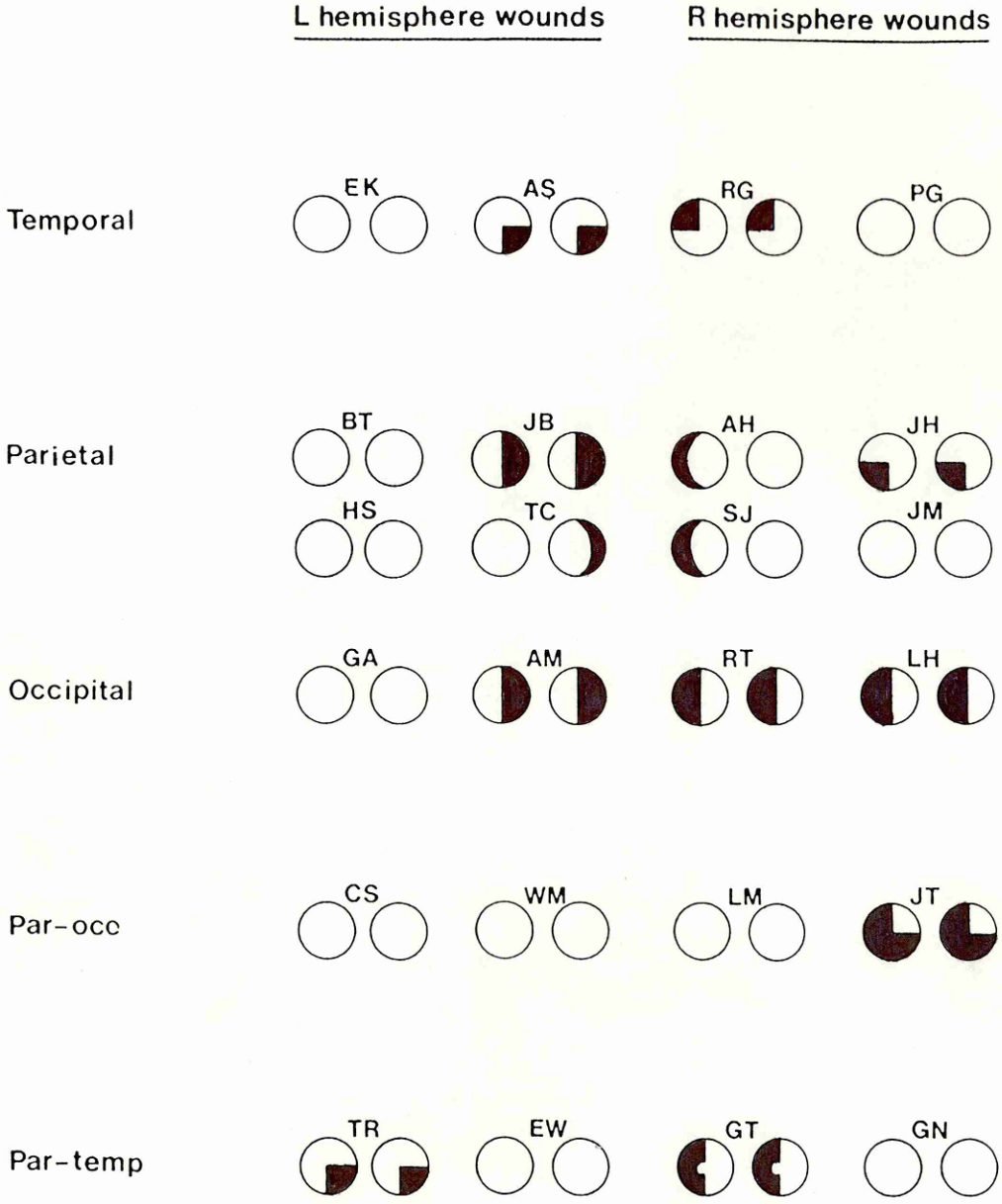


Fig 9:1 Visual fields of men with right or left hemisphere wounds according to the site of the missile injury.

(1961). Figs 9:2 and 9:3 indicate these wound areas to the right and left hemispheres respectively. (Details of each patient's subsequent neurosurgical treatment and neurological condition are given in the Appendix).

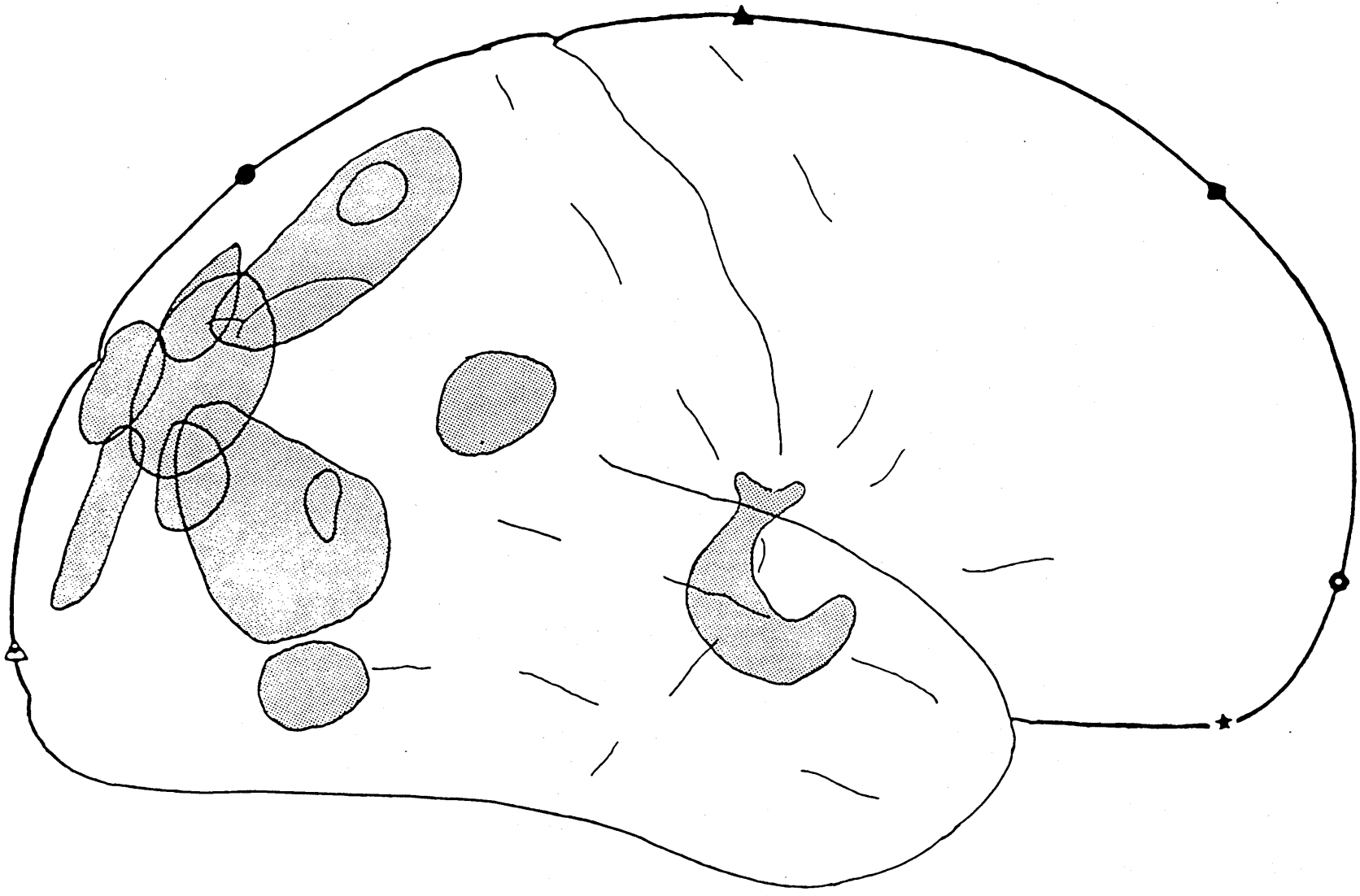
During a single session each patient viewed six types of stimuli: words, geometric designs, upright and inverted known faces, upright unknown faces and pattern reversal. The presentation sequence of the conditions was randomised with the exception that pattern reversal always concluded the session and inverted known faces always preceded upright known faces with at least one other type of stimulus trial being presented between the two (i.e. upright known faces were never shown immediately following inverted known faces). The recording procedure and the patients' viewing instructions were identical to those employed in the control studies described earlier. The right and left hemisphere injured patients' scores for recognition of inverted and upright known face slides are given below:

	Inverted				Upright			
	Known	Rec only	Nil	Misnamed	Known	Rec only	Nil	Misnamed
Right	5	2	31	4	20	6	14	2
Left	7	2	29	4	22	7	12	1

The known scores from this group of patients, with both upright and inverted faces, are considerably lower than those of the normal controls (see Chapter 6). Because the majority of normal subjects were younger than these missile injured men a small group of older males, aged between 62 and 65 years with a mean of 64 years, were tested for recognition with the same slides in the same experimental setting. Their

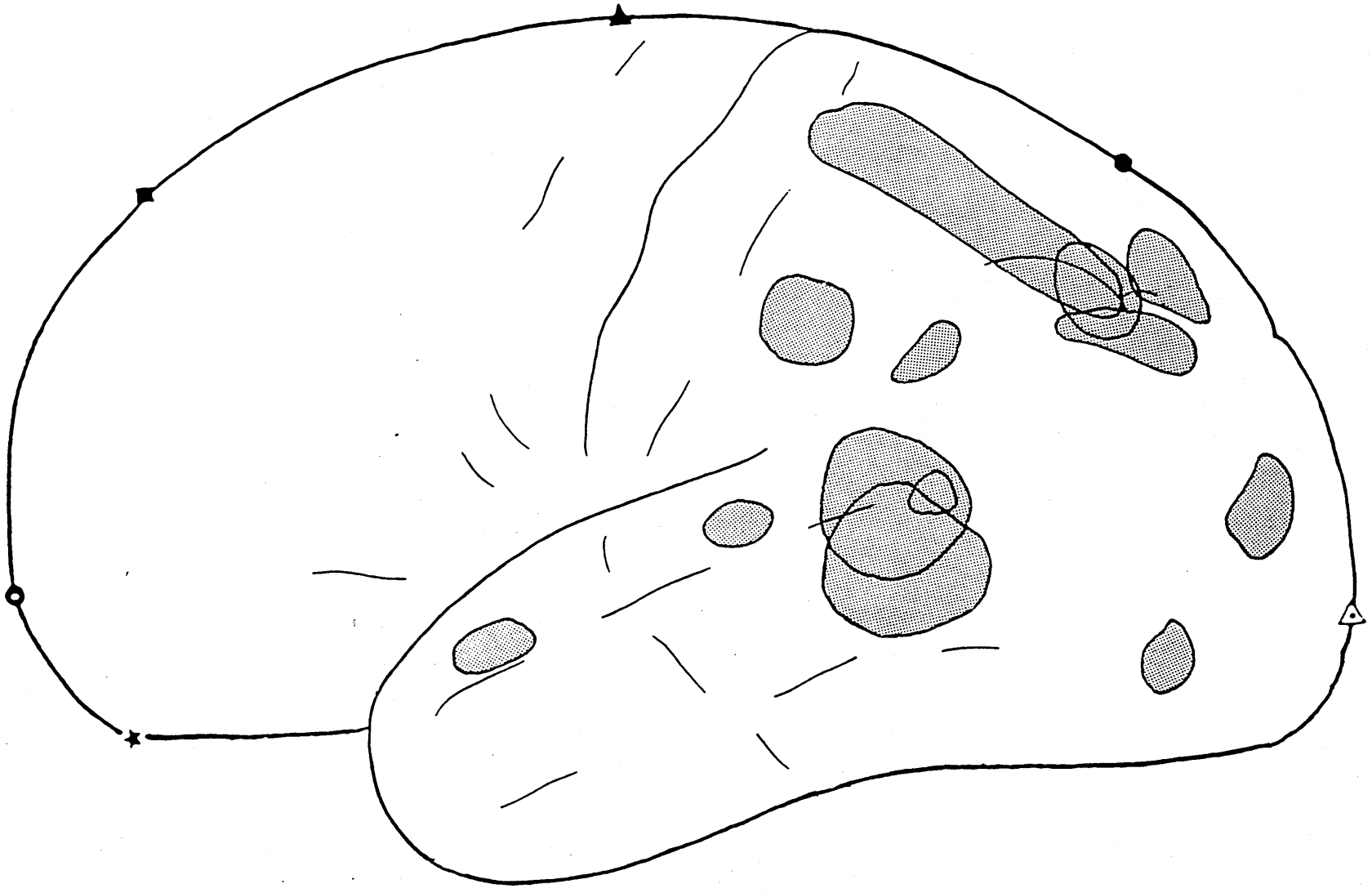
Right hemisphere injuries

Fig 9:2



Left hemisphere injuries

Fig 9:3



mean scores are shown below and it becomes obvious that the patients' scores are in fact comparable with those of normal men of a similar age.

Inverted				Upright			
Known	Rec only	Nil	Misnamed	Known	Rec only	Nil	Misnamed
6	2	30	4	22	5	14	1

Results

The data conform to a factorial analysis of variance (ANOVA) design with two between and three within subject factors as follows:

1. injured hemisphere (abbreviated to hemisphere)	between factor
2. area of wound (area)	"
3. type of stimulus (stimulus or condition)	within factor
4. side of recording (laterality)	"
5. site of recording electrodes (position)	"

ANOVAs were performed separately on each of the four dependent variables, namely P100 amplitude, P100 latency, P300 amplitude and P300 latency.

ANOVA: P100 amplitude

Table 9:4 shows the ANOVA probabilities for P100 amplitude, $p<0.05$ again being regarded as significant. There is a significant general effect of electrode position, $F(2,26)=10.04$, $p<0.001$ which interacts with the type of condition, $F(10,130)=7.70$, $p<0.0001$. There were no further interactions so the values have been collapsed across injured hemisphere, area of wound and laterality (side of recording). Table 9:5 and Fig 9:6 show the general position effect to be due to P100 being of highest amplitude in occipital regions compared to temporal and parietal areas. The position/condition effect is caused by this amplitude maximum being much more marked with pattern reversal, in the region of 2 uV.

P100 AMPLITUDE

Table 9:4

ANOVA Table of probabilities for Experiment 6.

Source	Degrees of freedom	F	Probability
Hemisphere	1	1.31	0.2735
Area	4	0.98	0.4504
Hem/area	4	0.94	0.4737
Condition	5	1.04	0.4024
Cond/hem	5	0.67	0.6509
Cond/area	20	0.90	0.5833
Cond/hem/area	20	0.59	0.9032
Error	65		
Laterality	1	3.87	0.0707
Lat/hem	1	1.88	0.1935
Lat/area	4	0.67	0.6237
Lat/hem/area	4	0.45	0.7730
Error	13		
Condition/laterality	5	1.18	0.3277
Cond/lat/hem	5	1.53	0.1926
Cond/lat/area	20	0.81	0.6923
Cond/lat/hem/area	20	1.22	0.2666
Error	65		
Position	2	10.04	0.0006 *
Pos/hem	2	0.86	0.4366
Pos/area	8	0.64	0.7369
Pos/hem/area	8	0.98	0.4702
Error	26		
Condition/position	10	7.70	0.0000 *
Cond/pos/hem	10	1.15	0.3337
Cond/pos/area	40	1.25	0.1751
Cond/pos/hem/area	40	0.69	0.9160
Error	130		
Laterality/position	2	1.55	0.2314
Lat/pos/hem	2	0.94	0.4046
Lat/pos/area	8	0.97	0.4810
Lat/pos/hem/area	8	1.04	0.4298
Error	26		
Condition/laterality/pos	10	0.55	0.8552
Cond/lat/pos/hem	10	0.44	0.9215
Cond/lat/pos/area	40	0.87	0.6958
Cond/lat/pos/hem/area	40	0.69	0.9119
Error	130		

P100 AMPLITUDE Effect of Position and Condition

	T6	P4	O2	T5	P3	O1
UPRIGHT KNOWN FACES	4.7uV	4.8	6.0	3.8	4.3	5.2
UPRIGHT UNKNOWN FACES	4.7	5.3	6.8	3.8	4.1	6.2
WORDS	4.6	4.2	4.8	4.0	3.7	4.3
INVERTED KNOWN FACES	4.2	4.4	5.5	3.8	3.9	5.0
GEOMETRIC DESIGNS	5.3	5.3	6.4	4.6	3.9	5.6
PATTERN REVERSAL	4.8	4.5	8.5	5.0	3.7	8.4

Table 9:5 Amplitude of P100 at the six electrode positions (irrespective of hemisphere and area of injury) under the six stimulus conditions.

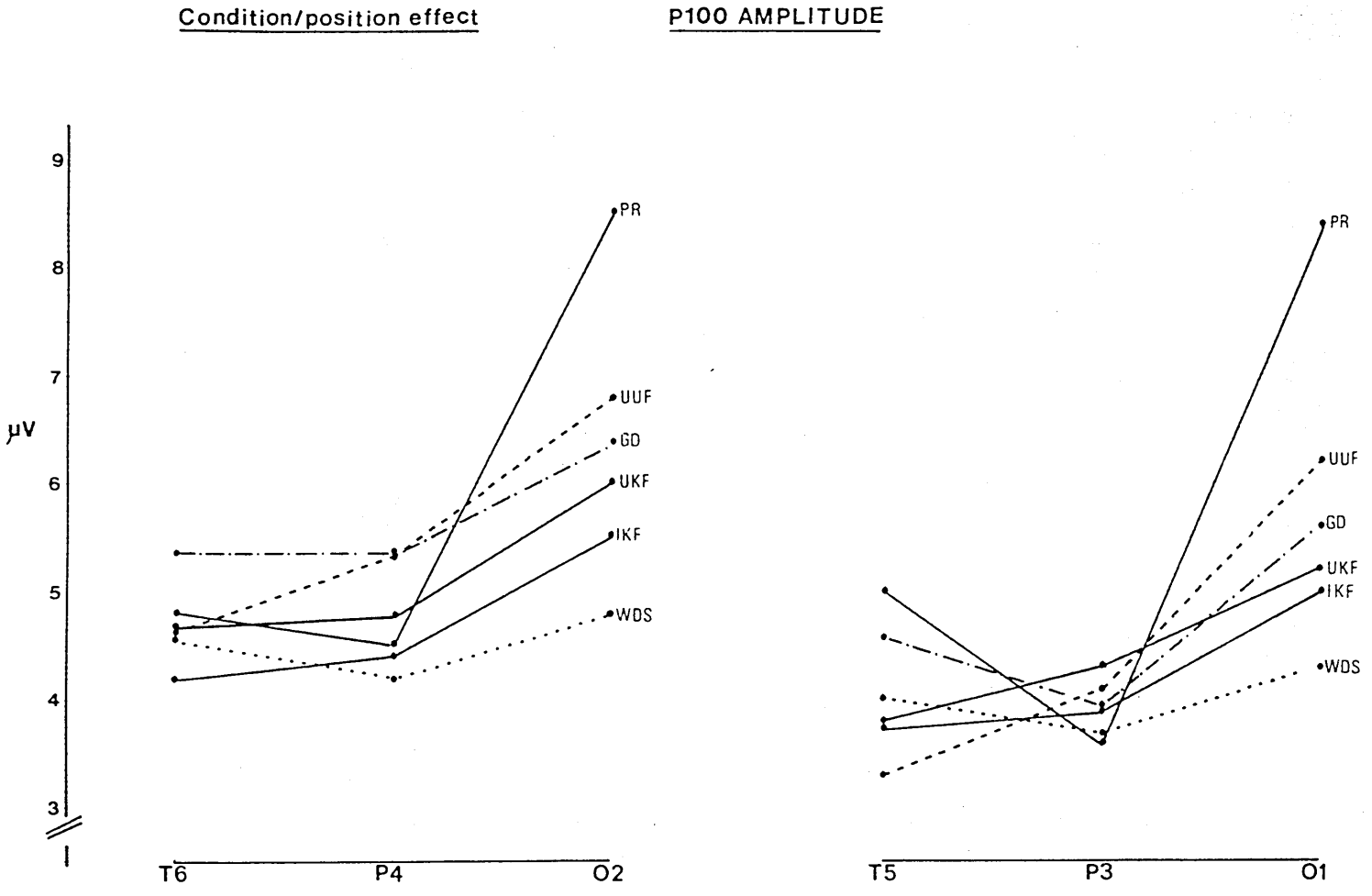


Fig 9:6 Amplitude of P100 at the six electrode positions (irrespective of hemisphere and area of injury), under the six stimulus conditions.

ANOVA: P100 Latency

Table 9:7 gives the ANOVA probabilities for P100 latency and Table 9:8 shows the mean P100 latency values for the type of condition, side of the electrodes and the patient's injured hemisphere. There is a significant general condition effect ($F_{5,65} = 4.77$, $p<0.001$. As there are no interactions with condition the mean P100 latencies for each type of stimulus have been calculated disregarding all other variables and are as follows:

Upright known faces	107.2 ms
Upright unknown faces	105.5 ms
Words	94.3 ms
Inverted known faces	106.9 ms
Geometric designs	89.9 ms
Pattern reversal	97.0 ms

The effect is therefore due to P100 occurring earlier with words, geometric designs and pattern reversal compared to the three types of face slides, in the region of 9 to 16 ms.

There is a general laterality (side of recording) effect, $F_{(1,13)} = 8.67$, $p<0.05$. The mean latency of the right and left sided electrodes is 98.5 ms and 103.9 ms respectively, so the effect is due to the left hemisphere responding slightly later (by 6 ms) than the right side. This laterality effect interacted with hemisphere (side of injury), $F_{(1, 13)} = 7.22$, $p<0.05$. The table below gives the mean P100 latencies from each hemisphere, for both right and left injured patients, disregarding other variables.

Left hemisphere injured		Right hemisphere injured	
Left electrodes	Right electrodes	Left electrodes	Right electrodes
103.7 ms	104.1 ms	93.9 ms	103.1 ms

P100 LATENCY

Table 9:7

ANOVA Table of probabilities for Experiment 6.

Source	Degrees of freedom	F	Probability
Hemisphere	1	0.92	0.3559
Area	4	2.41	0.1021
Hem/Area	4	0.42	0.7936
Error	13		
Condition	5	4.77	0.0009 *
Cond/hem	5	1.02	0.4125
Cond/area	20	0.92	0.5596
Cond/hem/area	20	0.98	0.4971
Error	65		
Laterality	1	8.67	0.0114 *
Lat/hem	1	7.22	0.0186 *
Lat/area	4	3.52	0.0373 *
Lat/hem/area	4	2.75	0.0739
Error	13		
Condition/laterality	5	0.69	0.6303
Cond/lat/hem	5	2.54	0.0370 *
Cond/lat/area	20	2.33	0.0055 *
Cond/lat/hem/area	20	3.65	0.0000 *
Error	65		
Position	2	14.51	0.0001 *
Pos/hem	2	2.71	0.0853
Pos/area	8	1.58	0.1788
Pos/hem/area	8	1.30	0.2874
Error	26		
Condition/position	10	0.77	0.6547
Cond/pos/hem	10	1.49	0.1484
Cond/pos/area	40	1.30	0.1370
Cond/pos/hem/area	40	1.35	0.1083
Error	130		
Laterality/position	2	2.49	0.1024
Lat/pos/hem	2	2.26	0.1246
Lat/pos/area	8	2.10	0.0732
Lat/pos/hem/area	8	1.44	0.2262
Error	26		
Condition/laterality/pos	10	1.08	0.3830
Cond/lat/pos/hem	10	1.01	0.4383
Cond/lat/pos/area	40	1.05	0.4121
Cond/lat/pos/hem/area	40	0.93	0.5950
Error	130		

P100 LATENCY Laterality/Hemisphere effect

		L sided injury					R sided injury				
		L temp	L par	L occ	L p-occ	L p-temp	R temp	R par	R occ	R p-occ	R p-temp
Upr. known faces	R electr	128.7	97.2	113.3	137.4	104.2	106.1	89.7	101.2	144.0	127.0
	L	138.6	88.9	123.1	129.2	91.0	103.9	86.4	86.3	122.6	94.0
Upr. unknown faces	R	119.9	111.3	111.1	132.8	91.9	113.8	97.3	94.3	96.8	120.9
	L	129.0	103.1	118.6	122.0	83.7	110.5	94.8	94.3	91.8	88.2
Words	R	89.2	90.7	93.9	79.0	98.5	97.8	88.7	95.9	153.0	83.3
	L	88.4	91.1	114.5	86.5	98.5	108.5	80.8	93.4	86.4	83.3
Inv. known faces	R	138.7	94.9	107.6	130.1	107.8	102.6	93.6	111.1	141.0	72.2
	L	118.1	95.3	123.1	135.9	96.3	98.0	92.3	101.2	123.7	72.2
Geom. designs	R	99.0	76.9	103.7	85.4	89.5	87.1	83.3	78.9	138.5	80.3
	L	94.8	97.9	113.6	82.9	78.8	86.4	77.9	79.0	98.1	80.3
Patt. reversal	R	92.1	97.0	107.0	97.1	98.5	89.9	99.7	93.6	118.5	92.1
	L	86.3	94.5	88.0	111.1	88.6	86.8	93.5	114.9	98.7	90.3

Table 9:8 Latency of P100 (from right and left sided electrodes) according to the hemisphere and area of missile injury, under the six stimulus conditions.

The laterality/hemisphere interaction is due to P100 occurring earlier from the left sided electrodes, compared to the right sided ones, in patients with right sided lesions.

There is also a laterality/area interaction, $F(4,13)=3.52$, $p<0.05$. The table below shows the mean P100 latency according to the side of recording and area of injury, without inclusion of any other variables.

	Area of injury				
	Temporal	Parietal	Occipital	Par-occipital	Par-temporal
R electrodes	105.4	93.3	101.0	121.1	97.2
L electrodes	104.1	91.3	104.1	107.4	87.1

The significant effect seems to be due to P100 occurring later from the right sided electrodes specifically in patients with parieto-occipital injuries (and to a lesser extent in patients with parieto-temporal wounds). As there was no laterality/hemisphere/area interaction, this is true for patients whichever hemisphere was injured.

There is also a significant condition/laterality/hemisphere effect, $F(5,65)= 2.54$, $p<0.05$. The table below gives the mean P100 latencies for the two groups (right and left hemisphere injured) showing the right and left sided electrodes under each type of condition.

	Left sided injured patients		Right sided injured patients	
Electrodes:	Left	Right	Left	Right
UKF	114.2	116.2	98.6	113.6
UUF	111.3	113.4	95.9	104.6
WDS	95.8	90.3	90.4	103.7
IKF	113.7	115.8	97.5	104.1
GD	93.6	90.9	84.3	93.6
PR	93.7	98.3	96.8	98.8

The values have been plotted in Fig 9:9 and this interaction appears to be due to the difference between right and left sided electrodes in right hemisphere lesioned men during the upright known face condition. With this type of stimulus the right side responds 15 ms later than the left. The upright unknown face condition shows a similar effect, in the same direction, but to a lesser degree.

There was a significant condition/laterality/area interaction, $F(5, 65) = 2.33$, $p<0.01$. Table 9:10 gives the mean P100 latencies for right and left sided electrodes during each condition with the patients classified according to the injured area. From this table the mean differences between the right and left sided electrodes have been calculated and are shown in Table 9:11. The values indicate that the condition/laterality/area interaction is caused by patients with parieto-occipital injuries having later P100 responses in the right hemisphere during words and geometric designs, and patients with parieto-temporal injuries also having a right hemisphere P100 delay during upright known faces and upright unknown faces. This result also interacted with hemisphere for there was also a condition/laterality/hemisphere/area effect, $F(5,20) = 3.65$, $p< 0.0001$. Table 9:12 shows the mean difference between right and left sided electrodes, under each condition, for patients according to their injured hemisphere and site of lesion. The condition/laterality/hemisphere/area effect is due to the right sided delay occurring in patients with right hemisphere parieto-occipital and parieto-temporal injuries only, and not the left hemisphere injured group. Because there is no further interaction with electrode position this right sided delay is generalised and not limited to any specific recording site.

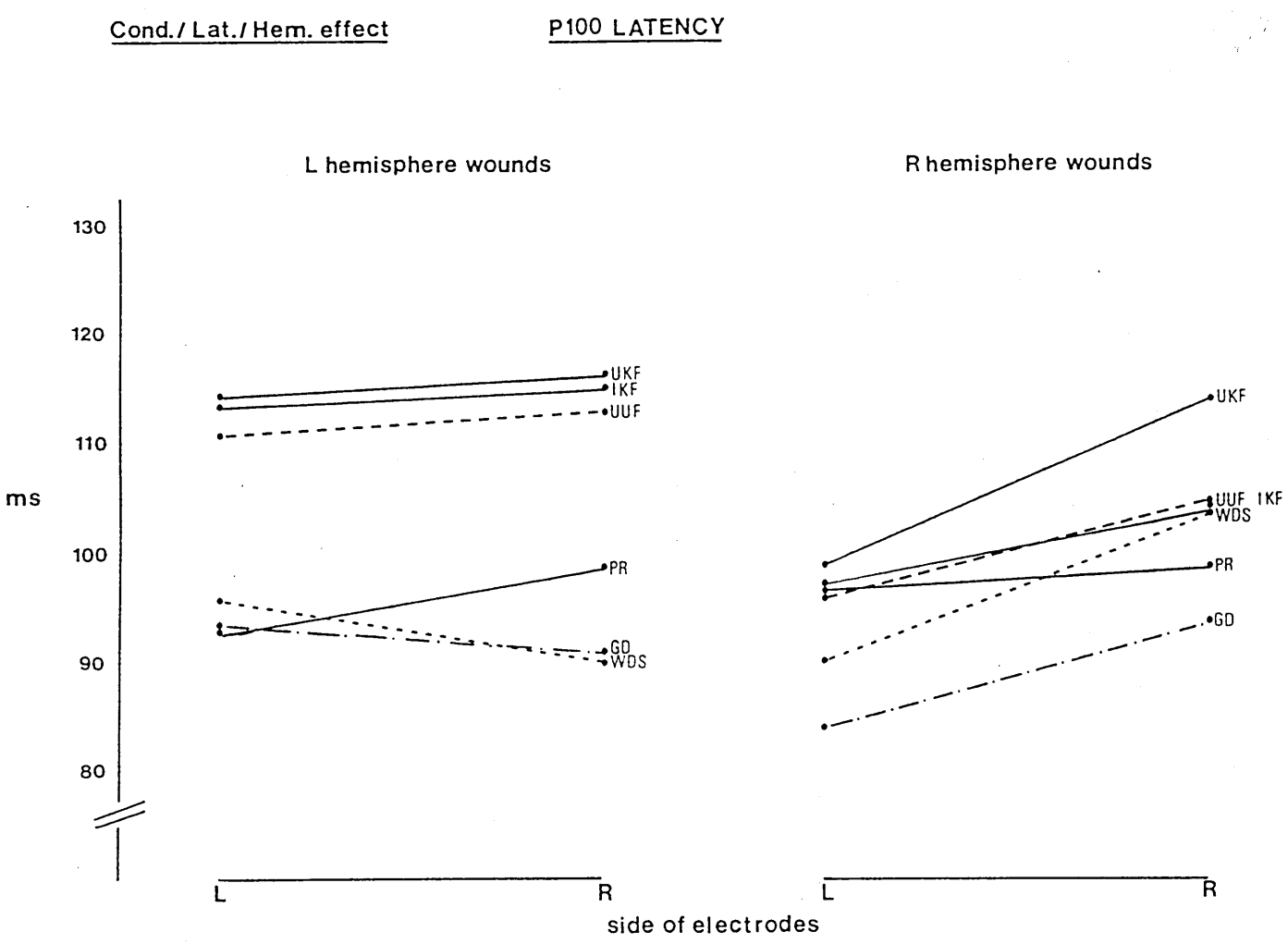


Fig 9:9 Latency (ms) of P100 at the six electrode positions (irrespective of hemisphere and area of injury) under the six stimulus conditions.

P100 LATENCY Condition/Laterality/Area effect

		Temporal	Parietal	Occipital	Parieto-occ	Parieto-temp
Upright known faces	R electrodes	117.4	93.4	107.2	140.7	115.6
	L	121.2	87.6	104.7	125.9	92.5
Upright unknown faces	R	116.8	104.3	102.7	114.8	106.4
	L	119.7	98.9	106.4	106.9	85.9
Words	R	93.5	89.7	94.9	116.0	90.9
	L	98.4	85.9	103.9	86.4	90.9
Inverted known faces	R	120.6	94.2	109.3	135.5	90.0
	L	108.0	93.8	112.1	129.8	84.2
Geometric designs	R	93.0	80.1	91.3	111.9	84.9
	L	90.6	87.7	96.3	90.5	79.5
Pattern reversal	R	91.0	98.3	100.3	102.8	95.3
	L	86.4	94.0	101.4	104.9	89.4

Table 9:10 Latency of P100 recorded from right and left sided electrodes according to the area of injury, under the six stimulus conditions.

P100 LATENCY Condition/Laterality/Area effect

	Temporal	Parietal	Occipital	Parieto-occ	Parieto-temp
UPRIGHT KNOWN FACES	3.8 ms	5.8	2.5	14.8	23.1*
UPRIGHT UNKNOWN FACES	2.9	5.4	3.7	7.9	20.5*
WORDS	4.9	3.8	9.0	29.6*	0
INVERTED KNOWN FACES	12.6	0.4	2.8	5.7	5.8
GEOMETRIC DESIGNS	2.4	7.6	5.0	21.4*	5.4
PATTERN REVERSAL	4.6	4.3	1.1	2.1	5.9

Table 9:11 The figures represent the difference in the latency of P100 between the right and left hemispheres.
* Values marked with an asterisk all indicate a right greater than left sided difference.

P100 LATENCY Condition/Laterality/Hemisphere/Area effect

	L sided injury					R sided injury				
	L temp	L par	L occ	L p-occ	L p-temp	R temp	R par	R occ	R p-occ	R p-temp
Upright known faces	9.9	8.3	9.8	8.2	13.2	2.2	3.3	14.9	21.4	33.0
Upright unknown faces	9.1	8.2	7.5	10.8	8.2	3.3	2.5	0	5.0	32.7
Words	0.8	0.4	20.6	7.5	0	10.7	7.9	2.5	66.6	0
Inverted known faces	20.6	0.4	15.5	5.8	11.5	4.6	1.3	9.9	17.3	0
Geometric designs	4.2	21.0	9.9	2.5	10.7	0.7	5.4	0.1	40.4	0
Pattern reversal	5.8	2.5	19.0	14.0	9.9	3.3	6.2	21.3	19.8	1.8

Table 9:12 Difference in latency of P100 between right and left sided electrodes for patients classified according to the hemisphere and area of injury, under the six stimulus conditions.

There is a general effect of position, $F(2, 26) = 14.51$, $p<0.0001$. The mean P100 latency for each electrode, disregarding all other variables, are as follows:

T6	103.5 ms
P4	104.7
O2	98.3
T5	97.8
P3	100.8
O1	95.7

The effect is therefore caused by P100 occurring bilaterally earlier in occipital regions, compared to temporal and parietal areas. There were no interactions with position, so this finding was present during all types of stimuli and in all patient groups.

ANOVA: P300 amplitude

Table 9:13 shows the ANOVA probabilities for P300 amplitude. There is a significant effect of condition, $F(5,65) = 11.05$, $p<0.0001$, which interacts with laterality (i.e. side of recording), $F(5,65) = 3.43$, $p<0.01$. There is also a significant general effect of electrode position, $F(2,26) = 17.48$, $p<0.0001$, which interacts with condition, $F(10,130) = 5.90$, $p<0.0001$. Because there were no other general effects or interactions, the P300 amplitude values covering condition, laterality and electrode position are shown in Table 9:14 and Fig 9:15, regardless of injured hemisphere and area of wound. The general effect of condition is due to P300 amplitude being of markedly lower amplitude during pattern reversal compared to the other five types of stimuli. In order to observe the condition/laterality interaction, Table 9:16 shows the difference in P300 amplitude between the right and left hemisphere for each type of condition. The interaction seems to be due to P300 clearly occurring of higher amplitude over the right side (at all electrode sites) compared to the left electrodes during upright known and unknown faces, to a lesser

P300 AMPLITUDE

Table 9:13

ANOVA Table of probabilities for Experiment 6.

Source	Degrees of freedom	F	Probability
Hemisphere	1	1.38	0.2618
Area	4	0.38	0.8194
Hem/area	4	0.71	0.5966
Error	13		
Condition	5	11.05	0.0000 *
Cond/hem	5	1.18	0.3300
Cond/area	20	1.17	0.3053
Cond/hem/area	20	0.84	0.6599
Error	65		
Laterality	1	3.26	0.0944
Lat/hem	1	1.37	0.2623
Lat/area	4	1.72	0.2050
Lat/hem/area	4	1.76	0.1972
Error	13		
Condition/laterality	5	3.43	0.0082 *
Cond/lat/hem	5	1.40	0.2357
Cond/lat/area	20	1.69	0.0586
Cond/lat/hem/area	20	1.23	0.2613
Error	65		
Position	2	17.48	0.0000 *
Pos/hem	2	1.41	0.2624
Pos/area	8	0.71	0.6813
Pos/hem/area	8	1.22	0.3265
Error	26		
Conditon/position	10	5.90	0.0000 *
Cond/pos/hem	10	0.93	0.5113
Cond/pos/area	40	0.67	0.9253
Cond/pos/hem/area	40	1.38	0.0893
Error	130		
Laterality/position	2	1.92	0.1668
Lat/pos/hem	2	3.36	0.0502
Lat/pos/area	8	0.89	0.5347
Lat/pos/hem/area	8	0.88	0.5447
Error	26		
Condition/laterality/pos	10	0.93	0.5091
Cond/lat/pos/hem	10	0.93	0.5051
Cond/lat/pos/area	40	0.91	0.6206
Cond/lat/pos/hem/area	40	0.72	0.8861
Error	130		

P300 AMPLITUDE Condition/Laterality/Position

	Right electrodes			Left electrodes		
	T6	P4	O2	T5	P3	O1
UPRIGHT KNOWN FACES	11.5	8.4	12.3	10.0	6.5	11.1
UPRIGHT UNKNOWN FACES	11.1	7.3	11.2	9.9	5.9	10.2
WORDS	7.7	6.2	10.3	8.9	5.5	11.3
INVERTED KNOWN FACES	10.7	8.1	11.6	10.1	6.6	10.9
GEOMETRIC DESIGNS	8.3	7.0	9.6	7.8	5.4	8.4
PATTERN REVERSAL	3.6	3.6	4.9	3.9	3.4	5.5

Table 9:14 Amplitude of P100 recorded from right and left sided electrodes (irrespective of hemisphere and area of injury) under the six stimulus conditions.

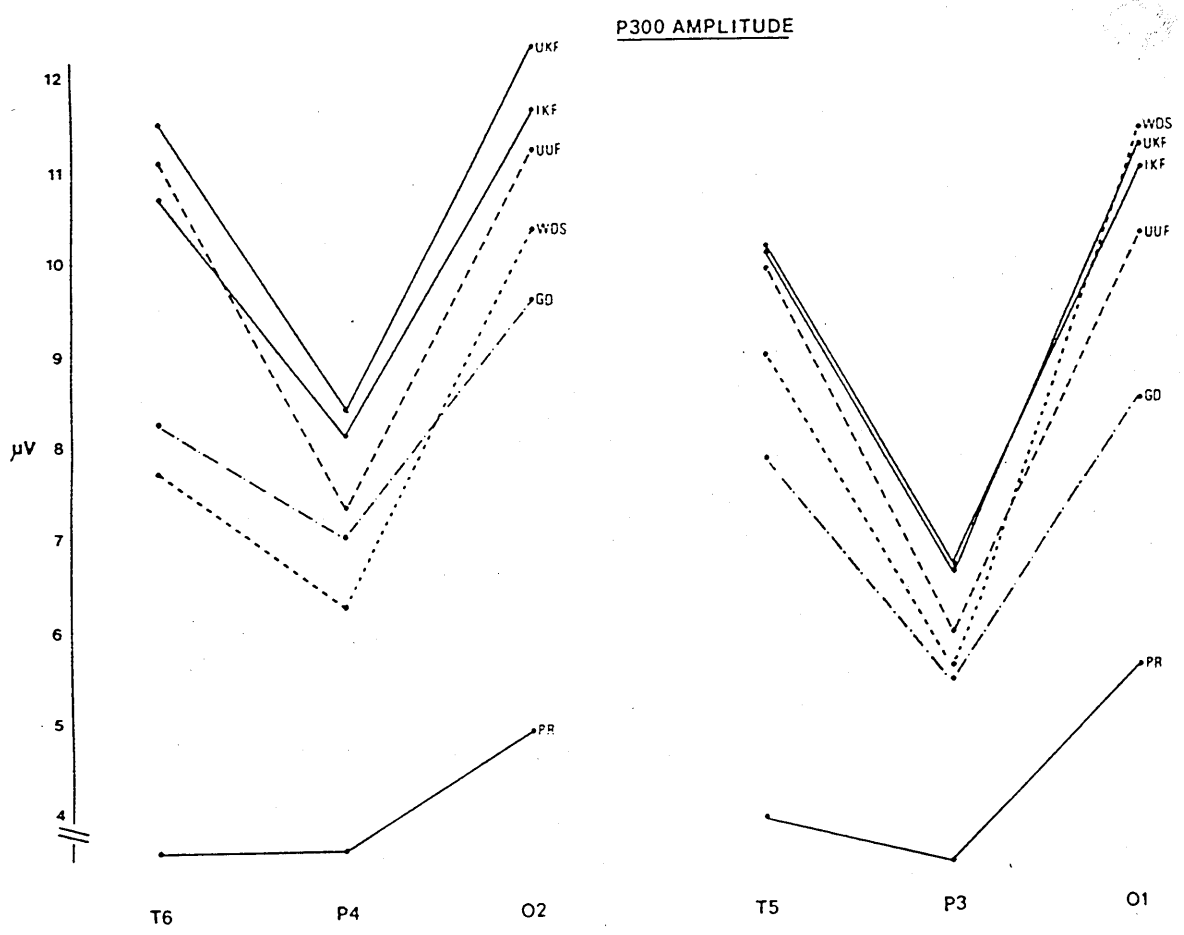


Fig 9:15 Amplitude (uV) of P300 from the six electrode positions (irrespective of hemisphere and area of injury) under the six stimulus conditions.

P300 AMPLITUDE lat Condition/~~position~~ effect

	Temporal	Parietal	Occipital
Upright known faces	1.5	1.9	1.2
Upright unknown faces	1.2	1.4	1.0
Words	1.2 *	0.7	1.0 *
Inverted known faces	0.6	1.5	0.7
Geometric designs	0.5	1.6	1.2
Pattern reversal	0.3 *	0.2	0.6 *

Table 9:16 Difference in amplitude of P300 between right and left hemispheres at the three recording sites (irrespective of hemisphere and area of injury) under the six stimulus conditions. All differences are right greater than left except those marked *

degree with inverted known faces and geometric designs, but not consistently during words and pattern reversal.

The general effect of position (which can be seen in Fig 9:15) is due to P300 appearing of much higher amplitude in temporal and occipital regions than in parietal areas. The position/condition interaction is caused by pattern reversal not showing this so obviously, with temporal and parietal regions showing fairly similar amplitudes.

ANOVA: P300 latency

Table 9:17 shows the ANOVA probabilities for P300 latency. There are three significant general effects of P300 latency as follows: injured hemisphere $F(1,13)= 6.28$, $p< 0.05$; area of injury $F(1,13)= 6.12$, $p< 0.01$ and condition $F(5,65)= 8.29$, $p<0.0001$. As there are no further interactions Table 9:18 gives the P300 latency to include hemisphere, area and condition but not laterality (side of recording) or electrode position. To examine the general hemisphere effect P300 latency has been calculated separately for patients with right and left sided injuries, disregarding all other variables. The mean latencies are 317.1 ms and 294.9 ms respectively and so the effect is due to those patients with right sided injuries having generally (and therefore bilaterally) slower P300 latencies (in the region of 22 ms) than the left injured group. This can be seen more clearly in Fig 9:19 which gives the latency of P300 for the patient's injured hemisphere and the site of the lesion.

The general effect of area can be seen from the mean latencies at the bottom of Table 9:18 (calculated disregarding all other variables except the site of injury) and in Fig 9:19. The effect is due to those patients with injuries to the occipital and parieto-occipital regions having bilaterally later P300s (by 20-50 ms) than the other groups. As

P300 LATENCY Table 9:17

ANOVA Table of probabilities for Experiment 6.

Source	Degrees of freedom	F	Probability
Hemisphere	1	6.28	0.0263 *
Area	4	6.12	0.0054 *
Hem/area	4	0.49	0.7434
Error	13		
Condition	5	8.29	0.0000 *
Cond/hem	5	1.61	0.1702
Cond/area	20	0.85	0.6513
Cond/hem/area	20	1.24	0.2500
Error	65		
Laterality	1	3.92	0.6953
Lat/hem	1	1.81	0.2009
Lat/area	4	1.09	0.4032
Lat/hem/area	4	0.49	0.7431
Error	13		
Condition/laterality	5	1.00	0.4221
Cond/lat/hem	5	1.92	0.1024
Cond/lat/area	20	1.09	0.3802
Cond/lat/hem/area	20	0.63	0.8792
Error	65		
Position	2	2.60	0.0936
Pos/hem	2	0.06	0.9464
Pos/area	8	0.51	0.8346
Pos/hem/area	8	0.63	0.7466
Error	26		
Condition/position	10	0.41	0.9392
Cond/pos/hem	10	0.33	0.9727
Cond/pos/area	40	1.02	0.4551
Cond/pos/hem/area	40	0.47	0.9963
Error	130		
Laterality/position	2	0.41	0.6657
Lat/pos/hem	2	1.47	0.2493
Lat/pos/area	8	0.48	0.8585
Lat/pos/hem/area	8	0.66	0.7184
Error	26		
Condition/laterality/pos	10	0.68	0.7434
Cond/lat/pos/hem	10	1.04	0.4117
Cond/lat/pos/area	40	0.46	0.9972
Cond/lat/pos/hem/area	40	0.74	0.8611
Error	130		

P300 LATENCY General effects of Hemisphere, Area and Condition

	Temporal		Parietal		Occipital		Par-occip		Par-temp		
Injured hem	L	R	L	R	L	R	L	R	L	R	X of Cond.
Upright known faces	303.8	294.7	274.1	358.3	311.2	363.3	306.2	360.4	284.5	351.5	318.7
Upright unknown faces	302.0	324.2	300.3	322.6	349.7	361.4	338.6	359.8	281.2	330.2	324.2
Words	267.9	293.4	242.3	241.3	364.6	298.6	216.1	366.0	217.6	250.0	271.0
Inverted known faces	310.3	307.2	306.9	326.4	307.8	364.9	352.6	397.5	307.2	395.1	332.0
Geometric designs	293.3	313.6	259.6	262.8	293.9	346.8	367.3	304.3	291.1	308.9	296.5
Pattern reversal	292.4	261.1	270.7	248.8	227.9	220.2	342.2	310.9	261.1	240.5	267.1
X of area	296.4		284.5		317.5		335.2		293.2		

Table 9:18 Overall mean latency of P300 according to the patients' injured hemisphere and area of injury, under the six stimulus conditions.

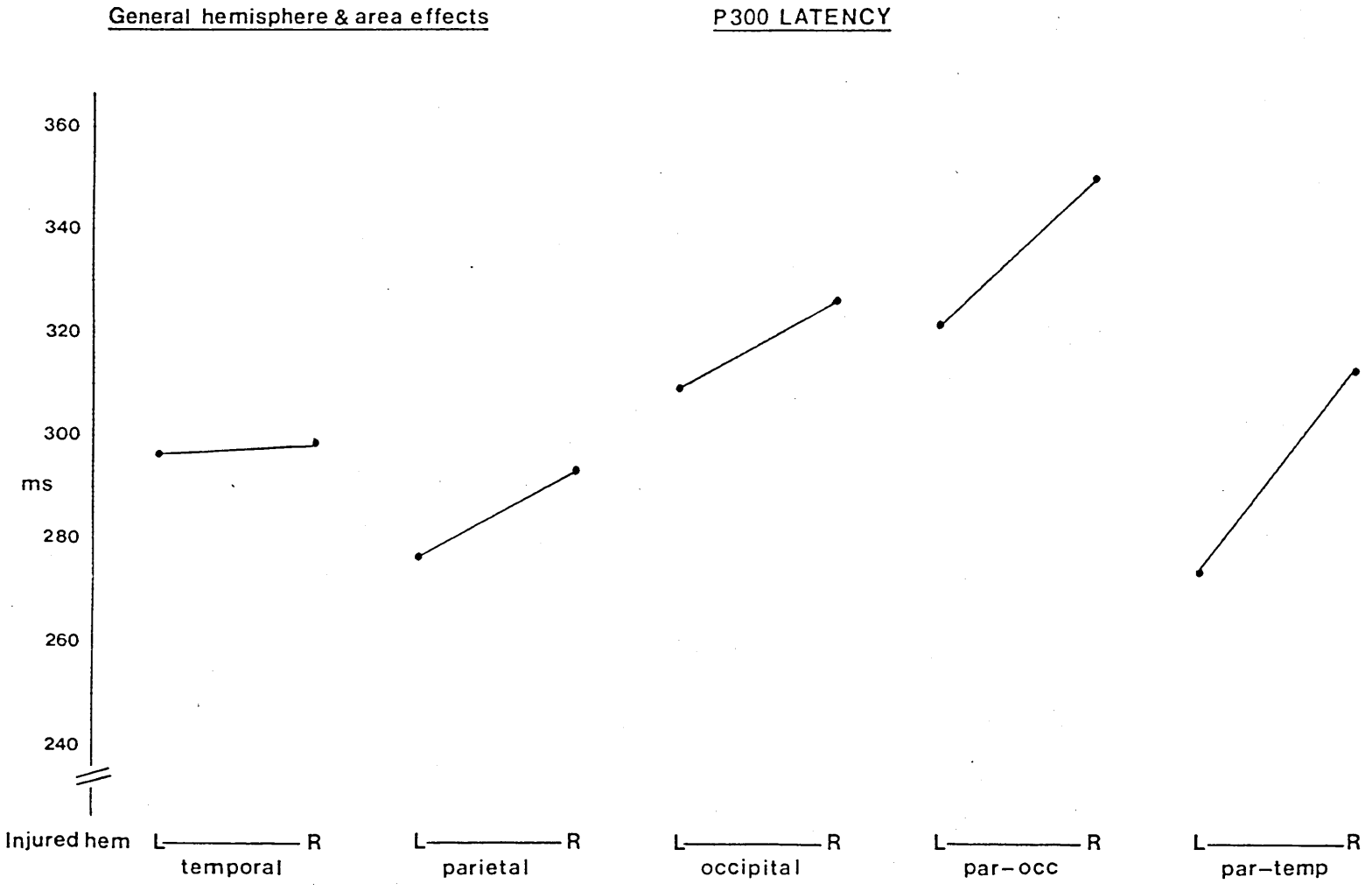


Fig 9:19 Overall mean latency (ms) of P300 plotted according to the patients injured hemisphere and area of injury

there was no hemisphere/area interaction this area effect is true for both right and left hemisphere injured patients.

The general effect of condition can be observed from the values on the right hand side of Table 9:18 which shows the mean P300 latencies just for condition, excluding all other variables. The latency is later during the three types of face stimuli (319, 324 and 332 ms) than with words (271 ms), geometric designs (296 ms) and pattern reversal (267 ms).

Discussion of Results

The statistical findings in this group of brain injured men show numerous significant effects, only some of which appear to be related to cerebral trauma. For clarity, those which replicate the previously reported results in normal subjects will be mentioned initially and then the effects which seem to be correlated with either the side or the area of the penetrating wound will be discussed.

Findings which replicate the normal control data.

Both P100 and P300 showed the same topographical differences as those reported for the normal right handed controls. P100 was larger in occipital areas than in temporal and parietal regions (particularly with pattern reversal) and the latency of this component was also similar to control values, being earlier with words and the two control stimuli than during the face conditions and again showing the shortest latency in occipital regions. P300 was of approximately equal amplitude in occipital and temporal areas and much reduced parietally. This component also showed a general amplitude difference depending on the type of stimulus (replicating the normal data) being, in order of magnitude, largest with

face stimuli, then words, geometric designs and pattern reversal.

Most importantly, P300, in these brain injured men, was clearly of higher amplitude on the right side compared to the left with upright known and unknown faces, to a lesser degree with inverted known faces and geometric designs, but not with words and pattern reversal. This finding replicates the same highly significant result found in normal right handers in Experiment 1. While such reproducibility signifies a certain robustness of the right sided amplitude superiority to face stimuli, it also poses the question why, with the inclusion of patients with right hemisphere damage, this effect still remains highly significant and apparent at all electrode sites. Such a result suggests that the source responsible for the amplitude asymmetry may lie in deep cortical structures unaffected by survivable missile injury. (However, it should be remembered that no patient suffered from prosopagnosia as a result of his head wound, and if P300 is specific to facial processing then the findings are compatible).

Findings related to brain injury

Before discussing these results it is important to point out that lesion experiments are subject to several limitations that may prevent straightforward interpretation. Firstly, a lesion may alter a given component, not because it destroys the cells that generate a certain potential, but because it interrupts pathways from other brain areas that provide necessary afferents to the generating site. Secondly, non-neural mechanisms (e.g. circulatory changes) may account for all or part of the E.P. change and thirdly, the size of the lesions are variable and therefore may produce effects due to overlapping damage to multiple structures. Finally, lesions may influence components indirectly via more

generalised effects (e.g. changes in arousal) and not by influencing the generators per se. However, as mentioned earlier, with respect to localisation missile injuries offer certain advantages over other types of brain lesions and although the above limitations may make interpretation difficult these patients represent the best source presently available for human experimentation.

Although the amplitudes of P100 and P300 were not significantly different, compared to normal values, in this group of brain wounded men the latency of both components did show alterations correlated with the side of the penetrating wound and the area of injury. P100 was generally delayed when recorded from the right side (compared to the left) in patients with right hemisphere parieto-occipital injuries during words and geometric designs, and in patients with right hemisphere parieto-temporal wounds during upright known and unknown faces. The latency was not, however, similarly affected in men with left sided damage. While patients with posterior lesions may be expected to have a distorted P100 component, it is not easy to explain why areas of cortical damage should produce a latency delay specific to the type of stimulation. One plausible, but tentative, interpretation is that there are stimulus specific anatomical locations at this early stage in visual processing. Several studies have provided evidence of a correlation between function and visual cortical organisation in the macaque monkey, using single unit recordings. Discrete areas of the striate cortex have been shown to be specifically responsive to line orientation and direction of movement (Hubel and Weisel, 1968 and 1979). The superior temporal sulcus has been shown to respond specifically to faces, spots, slits of light and shadows of objects (Bruce, Desimone and Gross, 1981) and to gratings, simple geometric stimuli, faces and complex three dimensional objects

(Perrett, Rolls and Caan, 1982). That there is a connection between these areas is evident from the study by Rockland and Pandya (1979) who described distinct topographic inputs to the superior temporal gyrus from the striate cortex in the rhesus monkey. While there are problems relating animal and human cortical data this evidence nevertheless suggests that cortical localisation of visual function could similarly occur in man. Indeed, Fried et al (1982), using electrical stimulation techniques on the exposed cortex, have provided evidence for discrete localisation of the perception of line orientation and faces within the right hemisphere of humans although there was no dissociation in the cerebral localisation of these two types of stimuli. (There was no simultaneous recording from the left side).

However, these studies offer no explanation as to why P100 should be altered under different stimulus conditions in patients with right, but not left, hemisphere damage, indicating functional differentiation within one hemisphere at an early perceptual level. Newcombe and Russell (1969) have compared the performances of patients with right or left hemisphere penetrating brain injuries on a facial recognition test and a visual maze learning task. Patients with right sided lesions performed at a lower level than those with left sided injury on both tasks but none of the right hemisphere group who showed defective facial recognition exhibited correspondingly defective visual maze learning. The neurological basis of the two deficits also tended to be different because the patients with defective facial recognition had posterior temporal lobe injuries with an associated left upper quadrantic visual field defect, while those who performed defectively on visual maze learning generally had posterior parietal lesions with an associated left hemianopia. The

authors however could not decide whether the deficits were due to visual perceptual (early) or visual memory (late) impairment. Therefore, although Newcombe and Russell's results correlate well with the present electrophysioloigcal findings they cannot be regarded as evidence specifically related to P100 rather than to P300.

Evidence of early, asymmetrical perceptual processing comes from two experiments, both involving thalamotomies, by Ojemann (1977) and Vilkki and Laitinen (1974). Unfortunately, these reports cannot contribute to the discussion on hemispheric functional differentiation because each study only presented one type of non-verbal stimulus. Ojemann (1977 and 1979) describes the effects of ventrolateral thalamic stimulation during right or left stereotaxic thalamotomy for the treatment of patients with dyskinesia. Patients were tested for verbal ability with an object naming task and for non-verbal processing by presentation of slides showing 16 and 24 point shapes. Interference to language and short term verbal memory occurred only with left thalamic stimulation while an effect on non-verbal, visuospatial material was present with stimulation to the right thalamus. Vilkki and Laitinen (1974) assessed patients undergoing right or left thalamotomy (by high frequency electrocoagulation for Parkinson's disease or hereditary intention tremor) both pre- and post-operatively with tasks of word fluency, receptive and expressive verbal efficiency, face recognition and face matching. Verbal performance deteriorated significantly after left thalamotomy but not at all after a lesion on the right. Face recognition was not altered by right or left sided surgery suggesting that thalamotomy to either side does not impair memory for faces. Performance time was prolonged in the face matching task in both patient groups, indicating that thalamotomy may disturb visual searching or perceptual speed irrespective

of the side of surgery. Most importantly, the number of errors in the face matching test increased significantly more after right, compared to left, sided lesions with the patients who made many errors appearing to identify a face by just a few features that were easy to isolate and verbalise yet too general to be reliable as discriminatory cues (e.g. a man, straight hair with a parting). Right thalamotomy may therefore cause inattention to the discriminatory cues necessary for the rapid perception of faces. Both this study and that by Ojemann (1977) strongly suggest that there is a functional difference between the two thalami (i.e. at an early stage in processing) related to hemisphere dominance at the cortical level, with right, but not left, sided lesions affecting non-verbal, visuospatial and face stimuli.

The possible influence of visual field defects upon the latency of P100 must be considered. The fields for each patient are given in Fig 9:1 which shows that the defects between the right and left parieto-occipital and parieto-temporal groups are not exactly comparable, the right hemisphere wounded men having a greater degree of visual loss. Although patients were asked to fixate centrally it could be argued that a preference for left to right scanning of non-verbal material (Braine, 1968) would impede patients with right sided injury and associated left visual field defects more than those with left hemisphere wounds and right visual field loss, consequently affecting the latency of P100 in the former but not the latter group. Although this theory could prove tenable if P100 had shown a consistent delay across conditions it fails to explain the variability in latency recorded under different stimulus presentations. Therefore, any contribution from visual defects may be ruled out.

The latency of P300 was also affected by the side of the wound, for it was generally delayed during all types of stimuli but only from patients with right hemisphere injuries (wherever the specific area of damage). It should be noted that P300 was later from both the right and the left sided electrodes in this group. Until now, it has been assumed that P300 is initiated as a bilaterally simultaneous event because an interhemispheric time difference has never been observed in normal subjects. Yet, the occurrence of a bilateral delay, apparently produced only by a right, and not left, sided injury (but see below) does suggest that this component may originate within the right hemisphere. However, this conclusion is not supported by recent studies investigating the neural generators of the evoked potential in man with simultaneous surface and depth recordings. Using implanted electrodes and visual stimuli (flashes), Velasco and Velasco (1985 and personal communication) report no interhemispheric latency difference in a component localised to the lateral geniculate body which occurs simultaneously with the scalp P300. Similarly, McCarthy (1985 and personal communication) using visual stimulation consisting of circles and crosses, has found no latency difference in the simultaneous, bilateral intracranial recording of a medial temporal waveform which covaries with the scalp P300.

A further significant result of a locus effect relating to P300 latency makes the overall picture even more complicated. This component was generally (and therefore bilaterally) delayed in patients with parieto-occipital and occipital lesions regardless of the side of the injury, providing evidence in contrast to the above suggestion of a right sided origin for P300. The finding that either a right or left hemisphere parieto-occipital or occipital injury can affect the latency throughout the contralateral side indicates that these two specific areas

within both hemispheres are necessary for the normal, bilateral production of this component.

A bilateral P300 delay can therefore be produced by either (i) a right hemisphere posterior missile wound or (ii) a right or left sided parieto-occipital/occipital injury. If the present knowledge of functional cerebral localisation is considered these two findings are not in fact mutually exclusive. There is clear evidence to indicate that early visual processing in man occurs in the primary receiving areas of the striate cortex. As cognition must follow perception, P300, (if it is related to cognitive processing) is likely to be initiated as a consequence of visual input within the occipital cortex. The development of right temporal lobe dominance for visual functions in man has been postulated to involve striate-temporal cortical interactions which selectively "potentiate" or "load" inputs to the right temporal lobe from both primary projection fields (Mishkin, 1965). The generator of this later component could then lie within the right hemisphere but be dependent upon information from both primary visual projection fields. Consequently, the latency of P300 would be affected by disruption to either (i) the right or left striate cortex, or (ii) the right hemisphere association cortex.

In summary, the experimental findings in this group of missile injured men show, for both P100 and P300 amplitude, only results that replicate those reported previously with normal subjects. The side and site of the lesion had no effect upon the amplitude of either of these two components.

The latency of the early P100 component was significantly delayed from the right side in patients with right parieto-occipital and parieto-

temporal lesions according to the type of stimulus. This dissociation of the delay between certain conditions suggests that there may be stimulus specific cerebral organisation and functional differentiation within the right hemisphere at an early stage in visual processing.

Patients with right hemisphere wounds showed a generalised, and therefore bilateral, delay in P300 which may indicate that this component originates within the right hemisphere. Yet this wave was also bilaterally prolonged in patients with injury to the parietal-occipital and occipital areas, regardless of which hemisphere had received the missile wound. The latter finding, seemingly in contrast to the above hypothesis, suggests that these two regions are essential for the bilateral production of P300 at the normal latency. However, by taking into account the known location of early perceptual processing in man, these two results are compatible.

CHAPTER 10

GENERAL DISCUSSION

The work of this thesis has been concerned with research into electrical potentials evoked by differing types of visual stimulation with particular emphasis paid to the later components of the waveform recorded in response to face stimuli. Major aims have been to investigate hemisphere differences in the early and late components to different types of visual stimuli in normal subjects, the waveform variability in relation to age, sex and handedness, and the character of the evoked potential change in patients with cerebral dysfunction. It is now time to outline the main findings and to consider what questions this work has answered and what questions it has raised or left open. The relation of the results to previous studies by other workers must also be summarized and future proposals outlined.

The research was initiated by a preliminary study which confirmed that an evoked potential could be recorded in response to slides of faces, in a situation where subjects were not required to perform a task. The form and latency of the two positive components corresponded to P100 and P300 reported in the literature with the maximum amplitude occuring over the posterior temporal, parietal and occipital regions. This was a novel finding (Small, 1983); no previous study had reported an evoked potential produced by face stimuli.

Chapter 1 describes the first experiment which involved right handed subjects, on the assumption that they would be left hemisphere dominant for language and therefore right hemisphere dominant for non-verbal material. This study concentrated on P100 and P300 in response to

both known and unknown faces and two control conditions which included complex stimuli other than faces and a physical stimulus without cognitive content. While P300 was found to be larger over the right hemisphere during all conditions, it showed a greater right/left difference with face slides than to control stimuli. This was a highly significant result ($p < 0.001$) and suggests that the asymmetry is related to "facial factors" rather than complexity. No difference was found in either the latency or the amplitude of the response between known and unknown faces, an unexpected finding for Neville et al (1982) have reported a larger P300 to slides (of people, places and paintings) that were recognised as opposed to unrecognised. Because there was no differentiation between known and unknown faces the right hemisphere P300 amplitude superiority seems to represent processing a face irrespective of whether or not the viewer has had previous experience of it. It remains slightly disappointing that these two types of stimuli showed no difference because such a result could have been applied to the study of facial memory and towards an objective test of facial recognition.

P100 and P300 were different with regard to hemisphere asymmetry. P100 showed a right greater than left amplitude emphasis equally with all types of stimuli but P300 had an additional right sided superiority in response to slides of faces. As P100 is thought to reflect the physical properties of a stimulus, this finding supports the theory that P300 is in fact related to cognition. The results of the first experiment also suggested that the origins of these two components are not identical and that they are evoked by different aspects of a stimulus. P100 was of greatest amplitude occipitally (corresponding to the area of maximum amplitude to flash described by Kooi et al, 1965) whereas P300 was more

widespread, suggesting an alternative site of production, possibly within the association areas. Precise localisation of component generating sites is obviously limited by the use of surface electrodes and further research in this area may have to rely on intracranial techniques. The present work by McCarthy (1985) and Velasco and Velasco (1985), recording P300 from cortical depth probes in awake humans, should provide more direct answers.

Finally, this experiment with fifteen female and fifteen male subjects provided an opportunity to observe the effects of sex and age on the evoked potential. P100 was generally of higher amplitude in females and both P100 and P300 occurred earlier in women. Such results are difficult to explain by variations in skull thickness; hormonal differences may be influential. With advancing age P100 was smaller, yet P300 larger, in response to face stimuli. Comparison of the present results regarding sex and age with the findings of other workers proved difficult because previous studies have been limited to the evoked potential in response to pattern reversal. However, the analyses clearly indicate that significant differences do exist in relation to a subject's sex and age, emphasising the need to take such factors into consideration.

As there was a highly significant right greater than left amplitude asymmetry of P300 in the initial study on right handers the second experiment was carried out to discover whether this P300 superiority could reasonably be ascribed, in dextrals, to the function of processing faces which is assumed to be located within the right hemisphere. Left handers are known to have less definite speech lateralisation with a higher proportion of right sided or bilateral language representation (Branch et al, 1964; Milner, 1974; Strauss and Wada, 1983) and so, conversely, they must have more frequent organisation of non-verbal pro-

cessing within either the left or both hemispheres. A group of sinistrals should therefore show no significant P300 amplitude asymmetry (or alternatively a left greater than right emphasis) if the evoked potential superiority is indeed related to cerebral function.

Twenty-two left handers took part in Experiment 2 and in most respects the results parallelled those of the right handed controls. P100 and P300 showed similar mean amplitudes and latencies to those reported in the previous experiment indicating that the results are easily replicable. The most impressive finding was the absence of a significant right greater than left P300 amplitude asymmetry, nor was there a reversed effect. Even after further classification into familial and non-familial left handers (based on evidence that these two groups can be distinguished according to which hemisphere is dominant for speech) the results were the same. This negative finding in a group of left handers, who can be assumed to have less lateralised non-verbal representation, therefore supports the earlier theory that the P300 right sided superiority with face slides does reflect functional organisation.

The next most pertinent question to be asked was whether the P300 asymmetry, recorded in right handers, reflected a processing system specific to upright faces or a more general perceptual ability within the right hemishere. While the evoked potential to slides of geometric designs (presented in Experiment 1 to act as control "non-face" stimuli with cognitive content) indicated that the marked asymmetry was specific to faces, inclusion of inverted face slides would answer the question more directly. If the P300 amplitude asymmetry reflects a superiority for processing any type of complex stimuli, it should not be affected by inversion but if the asymmetry is specific to upright faces, inverting

the stimulus should reduce or eliminate any such effect. Tachistoscopic studies (Leehey et al, 1978; Young and Bion, 1981) have shown that processing upright and inverted faces can be differentiated because a clear left visual field advantage (right hemisphere) is seen with upright faces while inverted faces show no difference between right and left fields (i.e. left and right hemispheres respectively). The third experiment was therefore undertaken in an attempt to replicate, with electrophysiological techniques, the results from these tachistoscopic paradigms.

The subjects were the same right handed individuals who had previously participated in Experiment 1. On this occasion the stimuli consisted of the same known and unknown face slides presented at that time except that they were shown upside-down. Statistical analyses were carried out on the responses evoked by inverted known and unknown faces compared to upright known and unknown faces, and geometric designs. The results showed no difference in P100 between upright and inverted face conditions, a not unexpected finding because the physical features of the slides remained constant. P300, however, with inverted faces failed to produce the clear right sided emphasis previously observed with upright faces. As the slides did not differ physically this finding substantiates the theory that P300 is correlated with cognitive, rather than physical, parameters. It also indicates that the right hemisphere asymmetry seen with upright faces is related to vertical orientation, i.e. that there is a "speciality" for upright faces within the right hemisphere.

There was a clear difference in the overall amplitude of P300 between upright and inverted face conditions, the latter being markedly reduced. Although subjects found inverted faces much harder to recognise (reflected in their scores of 48% correct with inversion and 81% correct

with upright faces) this difference cannot be attributed to "recognition ability" because P300 showed no comparable amplitude difference between known (recognisable) and unknown (unrecognisable) upright faces. The amplitude decrease therefore seems to be associated with the orientation of the slides. The fact that the amplitude was bilaterally reduced by inversion implies that although the right hemisphere has a specificity for upright faces, such processing must occur, to some extent, in both hemispheres. This amplitude decrement replicates the finding by Perrett et al (1984) who describe a marked amplitude reduction in the firing of single neurones recorded from the macaque cortex in response to inverted (compared to upright) faces. Although no explanation for this decrease was offered by Perrett et al their future work on primates may discover why inverted stimuli produce such an effect.

The experimentation so far had been specific to the investigation of the V.E.P. waveform in response to non-verbal material. However, it is obvious that in man both cerebral hemispheres have a role in cognitive function and considerable evidence exists from lesion studies, commissurectomies and tachistoscopic studies in normal subjects to indicate that the dominant, usually left, side is more involved than the right with language. An interesting question therefore arose: would the previous right handers who showed a right greater than left asymmetry with non-verbal slides subsequently reveal a similar, but opposite superiority with linguistic stimuli?

Previous studies in this field have produced conflicting results, for example Shelburne (1972) and Friedman et al (1975) report no difference between right and left hemispheres yet Preston (1979) and Kutas and Hillyard (1982) describe higher amplitudes on the left in parietal

and temporo-parietal regions respectively. Although evidence for language related asymmetries therefore remains inconclusive, these studies provide a strong indication of an existing late component in response to verbal stimuli. Experiment 4 was subsequently undertaken to substantiate the presence of P300 to linguistic stimuli and to investigate any evidence of asymmetry. Fifteen of the original group of right handers viewed a series of slides consisting of common words.

Both P100 and P300 were evoked by verbal stimuli, confirming previous studies (Courchesne et al, 1978; Freidman et al, 1975; Kutas and Hillyard, 1982) which report the presence of both components in response to slides of words. Statistical analyses showed no significant results at all except for an interaction with P300 due to this component occuring with a higher amplitude over the left temporal region in female subjects compared to males. There was however no general P300 amplitude asymmetry for the whole group.

When compared to the values obtained with presentation to the same subjects of non-verbal material, P100 was of much lower amplitude and did not show the marked occipital maxima, being similar at all electrode sites. This finding could indicate either that the slides of words proved insufficient in eliciting the usual occipital response due to physical parameters or that the processing of verbal material is less localised. P300 was also of lower voltage when compared to the values obtained with non-verbal stimuli and, like P100, it occurred with equal amplitude at all sites. Taken together with the lack of an asymmetry, this suggests two possibilities (i) either that there is no clear lateralised, localised area for the processing of verbal material or that (ii) such function is located in deeper subcortical areas, not accessible to surface recordings.

Up to this point the work had focused on the variability of P100 and P300 in normal subjects, including the influence of handedness, sex and age and the differential effects found with six different types of visual stimuli. Such a collection of information gave the range of amplitude and latency values found in a normal population, allowing confident statistical comparisons to be carried out on patients with related neuropsychological deficits. The opportunity arose to examine a patient with prosopagnosia. This patient, R.B., initially presented in 1975 with difficulty in recognising familiar faces, difficulty matching patterns and a tendency to get lost in unfamiliar surroundings. There was a low density area in the right posterior parietal area on CT scan. In 1977 he was found to have a left upper homonymous quadrantanopia, an impaired ability to recognise details of facial features and on CT scan there was a right temporo-parietal lesion with an additional low density area above the left lateral ventricle. With formal neuropsychological tests it was noted that his prosopagnosia was not as severe as had been reported in other cases though there was ample evidence of a difficulty with recognising both unfamiliar and famous people. His problems were shown not to be due to either a generalised intellectual deterioration, a general derangement of visual spatial function or to a gross sensory deficit.

This patient's evoked potentials, in response to known and unknown faces, geometric designs and pattern reversal, were recorded in September, 1982. His results were compared to the mean values of the male, right handed controls who took part in Experiment 1. In respect to P100 amplitude, P300 amplitude and P300 latency there were no significant differences between the patient and the control group. Although R.B.'s

P300 latency in response to known faces seemed delayed it actually fell within the normal range.

P100, however, was generally slower by 30 ms during all four conditions in the patient compared to the normal subjects. It was bilaterally delayed, indicative of a disturbance within both hemispheres at an early, sensory level suggesting involvement of the pathways to the primary visual cortex. Although bilateral, the P100 delay was not symmetrical for the right hemisphere responded 8 ms later than the left side. The possibility of this latency difference being due to poor acuity or to the quadrantanopia could be ruled out because it occurred inconsistently across conditions. Compared to normal controls, who only showed a 2-3 ms interhemispheric time difference during known faces and pattern reversal, the patient showed the right sided delay with geometric designs and, very markedly so, with pattern reversal. That the varying stimulus conditions produced a dissociation in the P100 interhemispheric delay, unlike that found in the normal controls, infers that even at the early sensory input level there is stimulus specific cerebral organisation. This evidence for specificity in man correlates well with what is known about the primate cortex (Hubel and Weisel, 1968; Bruce et al, 1981; Perrett et al, 1982)

While these findings are in keeping with the patient's known difficulty with textured pattern matching they do not help to explain his deficit on face recognition. In one respect the results are consistent with the study by Fried et al (1982) who found perception of line orientation in humans to be localised within the right hemisphere, in the region of the parieto-occipital junction. However, Fried found no distinction in the cerebral localisation between perception of upright faces and line orientation, evidence which infers that there should in fact have been no

dissociation between the response to faces and geometric designs in this patient. However, other studies do suggest dissociations associated with these stimuli, e.g. Eslinger and Benton (1983).

The opportunity was also taken to examine a group of men who had received missile injuries during World War II. Twenty-four men took part, twelve with right and twelve with left hemisphere wounds. They were categorised according to the area of injury (temporal, parietal, occipital, parieto-temporal and parieto-occipital) with the numbers being evenly matched between right and left hemisphere groups. The statistical analysis was designed to evaluate differential effects between right and left sided lesions and possible differences related to the specific area of injury.

The results showed that although the amplitude of P100 and P300 was not significantly different in this group of patients compared to normal controls, the latency of both these components was altered. P100 was prolonged from the right hemisphere in patients with right parieto-occipital and right parieto-temporal missile wounds, the delay being variable depending on the type of stimulus. This finding suggests that functional differentiation occurs within the right hemisphere at an early stage in visual processing and, like the P100 latency change reported for the prosopagnosic patient, implies that the brain is stimulus specific in humans at this level of perception. Such evidence for early, asymmetrical processing correlates well with the studies by Ojemann (1977) and Vilkki and Laitinen (1974) who report that right, but not left, thalamic lesions interfere with the perception of visuospatial material and face stimuli in human subjects. Each of these studies only presented one type of

visual stimulus and therefore functional differentiation could not be assessed. However, the present suggestion of right hemisphere functional specialisation is supported by the findings of Newcombe and Russell (1969). Patients with right sided lesions performed less well on facial recognition and visual maze learning tasks than those with left sided injury, and performance deficits on the two tasks in the right hemisphere group could be differentiated. Further investigation of patients with circumscribed lesions, involving several different types of visual stimuli, would be worthwhile in an attempt to learn more about functional specialisation.

The group of missile injured patients also showed two other interesting effects. Men with right sided lesions, regardless of the precise site, showed a bilateral delay in P300 (while men with left hemisphere injuries did not), inferring that the origin of this component lies within the right hemisphere. However, P300 was also significantly later in patients with right or left parieto-occipital and occipital damage (i.e. regardless of which hemisphere had received the injury) suggesting that these regions within both hemispheres must be intact for a normal P300 latency. This latter finding appears to conflict with the previous result but can be explained by postulating that the right hemisphere may indeed be functionally dominant for visual processing but that such specialisation is dependent upon information from both the right and left primary visual cortex. The latency of P300 would then be disrupted by damage either to the right association cortex or to the right or left occipital regions.

For the future, the study of the primate visual system by, for example, Perrett et al (1984) and Bruce et al (1981) should suggest further lines of research, promoting convergence between human neuro-

psychology and animal neurophysiology. Further studies in man, using intracranial techniques and presentation of various types of visual stimuli, would certainly help towards understanding human functional organisation and stimulus specificity. Bilateral electrode implantation procedures, such as those by the Yale University group (i.e. Wood, McCarthy et al, 1984) may shortly define the origins of evoked potential components, particularly P300. Obviously, the opportunity for such experimentation is exceedingly rare but information regarding functional specialisation could also be gained using more conventional methods, by investigating patients with clearly defined lesions under several different types of stimulus conditions.

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APPENDIX

HAND PREFERENCE

APPENDIX A

NAME: _____ AGE: _____

Handedness	Left	Right
writing		
throwing (ball, darts)		
games (bat, racket)		
cutting with scissors		
brushing teeth		
striking a match		
hammering		

Has there been any change in preference?
Please specify when and why, and in what activity.

Is there a family history of left-handedness?

KNOWN FACES

APPENDIX B

Mohammed Ali
Eamon Andrews
George Brown X2
Jim Callaghan
Winston Churchill
John Conteh
Henry Cooper
John Curry
Charlie Drake
Duchess of Kent
David Essex
Marianne Faithful
Susan George
Vera Lynn X2
Glenda Jackson
Paul McCartney
Eric Morecombe
Humphrey Bogart
Mark Phillips
Princess Anne
Prince Charles
Princess Margaret
Prince Philip X2
The Queen
Queen Mother X2
Diana Ross
Freddie Starr
Telly Sevelas
Tommy Steele
Margaret Thatcher X2
Twiggy
Virginia Wade
Raquel Welch
Harold Wilson X2
Andy Williams
Ernie Wise

WORD STIMULI

APPENDIX C

snail
whale
bee
pig
crab
caterpillar
elephant
snake
kangeroo
lion
squirrel
camel
aeroplane

mouse
bear
dog
trumpet
piano
violin
airplane
boat
car
bus
hand
eye
pencil

lamp
ladder
nail
chair
door
tyre
bed
ring
book
button
banana
shoe

0	Calibration	
1	Preselected averaging formats for routine, clinical use	
2	" " " " "	
3	" " " " "	
4	Variable averaging format	
5	NCH	Number of channels (6)
6	NSW	Number of sweeps (42, 64 or 41 depending on the stimuli)
7	TIME	Sweep time (1000 ms)
8	DELAY	Delay time between trigger and start of sweep (0 ms)
9	EEG	Continuous display of on-going EEG.
A	AV	Start averaging
B	DISP	Display of stored average
C	O/P	Contents of average buffer printed and plotted
D	NAME	Entry of subject's name
E	PROC	Stored averages displayed for processing
F	STOP	Termination of program

NEXT	Displays next stored average
SINGLE	Displays a single channel
FIX	Scale factor linked to previous runs
FREE	Scale factor dissociated from previous runs
PRINT	Cursor latencies and amplitudes printed on teletype
FILTER	Three point moving average filter
O/P	Current run plotted and printed
PLOT	Current run plotted
AUTO	Reloads Autoprog program
STOP	Termination of program
DOWN	Scales down the display
UP	Reverses the effect of A
SUPER	Outputs data, superimposing plots
SUM	Current run summed into buffer
ENDSUM	Contents of sum buffer displayed

MISSILE INJURED PATIENT HISTORIES

* CT scans were not carried out on four patients due to the presence of a metallic scalp plate (BT, TC, GN and AM).

1.LM In March 1945, at the age of 22 yrs, this patient received a penetrating brain wound in the right parieto-occipital region, without loss of consciousness. Two days later the wound was debrided; an area of brain filled with pulp and bone chips was removed. On examination one month later he was found to have a left homonymous hemianopia but no sensory loss. In January 1946 the skull defect was repaired with a tantalum plate. Several readmissions occurred between 1948 and 1967 for review of headache and epilepsy which consisted of both grand mal and minor visual fits. During this time the patient reported difficulties in map reading, model construction, recognising faces and judging speed and distances. Detailed psychological examinations carried out in 1969 and 1981 showed a good performance on verbal tasks but marked impairment on visual perceptual and spatial tests. There was no evidence of generalised intellectual deterioration.

Present condition: A left homonymous hemianopia with perception of moving targets in the left upper quadrants. No sensory loss, weakness or ataxia.

2.EK The patient received a penetrating wound just anterior to the left ear with a compound fracture of the temporal bone in September, 1944, at the age of 24 years. The wound was debrided ten days later; a track leading into the floor of the temporal fossa was explored by a linear incision and a dural graft applied. Subsequently, he had complete paralysis of the left facial muscles, headaches, occasional attacks of giddiness and minor epileptic attacks at the rate of 3 to 4 per year consisting of a consecutive series of thoughts, usually nonsense words. These ceased in the 1950's. Skull X-ray in 1956 showed a metallic foreign body in the left temporal lobe approximately two centimetres from the surface. Intensive psychological investigation in 1964 reported that the only suggestion of selective impairment was a barely discernible difficulty in retaining verbal material.

Present condition: Full visual fields. No weakness, ataxia or sensory loss. CT scan showed a previous schrapnel injury with the entry wound in the left temporal fossa and a residual metallic foreign body in the region of the angular gyrus in the left temporal lobe.

3.BT At the age of 21 years, in March 1945, this patient had a penetrating wound in the left parietal region with only brief loss of consciousness. The following day the injury was debrided with bone and lacerated brain being removed from a track which passed directly down to a depth of four centimetres. Post-operatively he had a right homonymous hemianopia, slight paresis of the lower right face, sensory loss in the right arm and leg and some weakness in the right toes. On examination one

week later he was reported to have slight nominal dysphasia, a right attention hemianopia, profound loss to pin prick and of position sense and slight spastic weakness in the right leg. When seen at follow-up in 1964 the patient complained of occasional attacks of visual disturbance, errors in spelling and writing and some clumsiness of the right foot. However, on neurological examination there was no weakness or sensory loss. Psychological tests showed no sign of generalised intellectual deterioration; the only selective impairments were difficulty in learning new verbal material and a below average performance with block design. In 1969 difficulty with learning new material was still marked and there was impairment in right/left orientation. Follow-up examination in 1975 gave a similar picture.

Present condition: Full visual fields. Neurologically there was no weakness and the only sensory disturbance was impaired postural sense in the right foot.

4.AH This patient received a penetrating wound to the right posterior parietal region in July 1944, at the age of 29 years. Fourty-eight hours later the brain track was debrided to a depth of four centimetres with removal of many indriven bone fragments. Post-operative neurological examination revealed no abnormality except a slight right facial weakness especially with emotion and the patient's only complaint was that he found it difficult to find his way about. On examination two weeks later power and tone in the limbs were reported to be normal and no sensory deficits were found. Psychological testing showed "presence of intellectual loss chiefly in a spatial sense and three dimensional thought such as that required for block design and memory for position". Psychological follow-up in 1964 showed a difficulty in visual spatial tasks. When retested in 1969 he was impaired in some visual matching and recognition tests, was significantly impaired in personal right/left orientation and had considerable difficulty in learning both visually and tactually presented mazes. Neurological examination at this time revealed only a slight visual localisation difficulty in the left lower quadrant.

Present condition: Right visual field full; left, slight constriction of 12e isoptre. No weakness, ataxia or sensory loss. CT scan showed an old gunshot wound with bone deficiency in the right upper parietal region. There was a large cortical defect in the right upper parietal region with slight enlargement of the ventricles in keeping with the patient's age, but more localised dilatation in the right upper parietal region due to the wound.

5.JB This patient received four penetrating wounds in the left parietal area in March 1945, at the age of 22 years. At operation, nine hours after injury, a curved incision was made excising and uniting the four wounds. Brain matter and bone chips were removed. Postoperative motor and sensory testing was normal but there was a complete right homonymous hemianopia, right lower facial weakness, dyslexia, perseveration, acalculia and gross global dysphasia. In January 1946 the wound was again debrided and a metal foreign body removed. At this time dyscalculia, marked general dysphasia and topographical disorientation were noted. At follow-up in 1965 the patient reported headaches, impaired

retention of recently learned material, poor concentration, difficulty with speech and visual loss. On neurological examination he was found to have a right homonymous hemianopia and weakness with diminished sensation of the right arm and right leg. X-ray revealed a left parietal defect with shell fragments posteriorly placed in the left hemisphere. Psychological testing showed a dysphasic impairment and a slight selective impairment in constructional tasks. There was no evidence of a generalised memory deficit. When seen again in 1971, the residual dysphasia was still apparent in speech, reading and writing. Verbal memory was impaired and there was also evidence of a mild degree of topographical disorientation (which had been noted at the acute stage).

Present condition: Right homonymous hemianopia. No weakness of limbs. CT scan revealed an old gunshot wound in the left parietal region with severe disruption of the brain. There was an extensive area of low density reaching down to the left trigone and forward in the Sylvian fissure and region of the left temporal horn with several metallic fragments lying in the same area.

6.PG In February 1945, at the age of 19 years, this patient was hit by a machine gun bullet with an entry wound in the right zygomatic region and an exit wound in the right mastoid area involving the right middle ear, right facial nerve and right temporal lobe. The wound was debrided two days later, a large amount of necrotic cortex and many bone fragments were removed. A radical mastectomy was carried out ten days later. The skull defect was repaired with a tantalum plate in September 1946. He had occasional generalised epilepsy between 1947 and 1956, and between 1947 and 1965 he reported weakness of the right hand and right side of face, impaired memory and concentration and slowness in learning. On admission in 1965 neurological examination revealed only a slight right facial weakness. Formal psychological testing showed the patient to be very efficient in tests of memory and learning. The only anomalies were relatively less efficient sorting and a slightly perseverative tendency in verbal fluency tasks.

Present condition: Visual fields full. CT scan: metal plate over the right temporo-parietal bone. Pituitary fossa intact and apparently normal size. Neurological examination showed a right lower motor neurone facial palsy but no weakness, ataxia or sensory loss.

7.GT In July 1944, at the age of 23 years, this patient received a tiny penetrating wound just posterior to the right mastoid and a dural tear over the cerebellum. At operation three days later four bone chips were removed (three from the cerebellum) but no attempt was made to explore the wound track. Post-operative X-ray showed a m.f.b. (metallic foreign body) in situ (which had passed through the posterior part of the right lateral ventricle) but no remaining bone fragments. One week later the patient had minor cerebellar signs, a left homonymous defect and occasional twitching of the left side of the face. Five weeks after injury psychological testing showed impairment of memory, visual imagery and calculations. During re-examination at the end of September 1944 the quadrantic loss was still present and there was an inconstant left facial weakness. There was no follow-up until the present admission.

Present condition: A left hemianopic defect with macular sparing in both visual fields. CT scan and neurological state not available due to premature discharge.

8.JM This patient received a right posterior parietal penetrating wound in September 1944 when 32 years old. Forty-eight hours later the wound was debrided, the missile track sucked to a depth of three centimetres and three indriven bone chips removed. Post-operative X-ray showed no remaining bone fragments except one in the scalp. Three days post-operatively he had one isolated left sided fit. Five weeks later the patient was complaining of lack of coordination on the left side of his body and occasional brief periods when his surroundings felt distant. On examination power was slightly reduced in the left arm and the left leg and there was slight postural loss in the left arm and both big toes. The right visual field was constricted and the left, slightly dis-orientated. Subsequently, between February 1945 and 1960, he had attacks in which he felt tingling in his left arm spreading to the left leg followed by loss of consciousness for a few minutes. On neurological examination (1964) visual fields were full but there was a slight left hemiparesis and cortical sensory impairment in the left upper limb. Proprioception was slightly impaired in both feet and there was difficulty with visual localisation on the left.

Present condition: Visual fields full. Neurologically there was sensory loss in left hand and left foot with extinction to touch. Fine movements poor and light touch and pin-prick slightly blunted in the left hand. CT Scan: A large low density area in the right upper parietal region ex-tending to the vertex where there was a hole in the vault. Elsewhere there was evidence of marked involution with large ventricles and prominence of sulci. No metallic fragments seen.

9.JH In July 1941, at the age of 25 years, this patient was hit by a bullet in the right parietal region, associated with transient loss of consciousness and left hemiparesis. During surgery the following day the bullet was found to have produced a tangential wound of the skull, perforating the dura. The wound was debrided. He subsequently developed meningitis and hernia cerebri ten days later. On readmission in August 1942 neurological examination showed clumsiness on movement of the left hand, dulling to pin-prick over the whole of the left side of the body and marked loss of position sense and stereognosis in the left hand and foot. The findings were essentially the same at follow-up in August 1943 and October 1944. Visual field studies carried out in January 1945 showed an incomplete inferior left quandrantanopia. On examination in February 1949 there was still loss of sensation in the left hand and a definite inability to localise objects in the left visual field. The patient reported he had suffered from two types of epileptic attacks since 1942, the first beginning with jerking of the left side of the face (sometimes proceeding to a generalised convulsion with loss of consciousness) and the second type consisting of an uncomfortable sensation, a feeling of heat and visions of various scenes. On admission in 1969 neurological examination revealed a mild left hemiparesis with a hemisensory disturb-ance particularly affecting proprioception and cortical sensation in the

left hand. He had a left inferior quadrantanopia and difficulty localising in the left upper quadrant. His major convulsions ceased in 1959 but he still had occasional visual epileptic attacks. Psychological tests showed an impairment in tactile spatial abilities but no deficit in analogous visual tasks. Language skills were unimpaired and scores on general ability tests were above average. Reassessed in 1980 no significant changes were observed. At this time the patient reported that he was aware of a slight degree of topographical disorientation and topographical memory loss (e.g. he might take the wrong turning in his own house).

Present condition: There was a left inferior quadrantanopia. Neurological examination showed slight weakness in the left limbs and extensive sensory loss: postural loss in the left fingers and toes, pin-prick blunted on left, localisation very slow but accurate, atereognosis on left and no threshold to two point discrimination in the left fingers. CT scan revealed a large area of cerebral damage in the right parietal cortex with a small high density fragment lying in the brain in this region and moderate enlargement of the posterior horn in the right lateral ventricle.

10.SJ This patient received a severe bullet wound of the brain in July 1944 at the age of 29 years when a missile entered the right parietal region, posteriorly near the sagittal line, and passed forward to the right frontal lobe where it still lies. At the time there was an immediate paralysis down the left side of the body, some visual disturbance but no great alteration in consciousness. Surgery was carried out by the German army and subsequently by the French and American forces when the wound became infected. He was "all mixed up" mentally during this period which lasted approximately ten days. His hemiplegia gradually improved and he was able to walk by September 1944. He was not reasessed until 1968 when he reported that during the intervening years he had found difficulty in concentration and was very slow at calculating over a period of time. He had difficulty with the left hand, being unable to gauge its position accurately in space. He also reported difficulty with visual spatial tasks (e.g. spacing material badly when typing), finding his way around a new building and learning new material. On neurological examination there was a moderately severe left hemiparesis, hemianaesthesia, a right and left upper quadrantic hemianopia and a concentration impairment. Skull X-ray revealed a right high parietal defect close to the midline with a bullet lying in the right frontal region with some calcification or rusting around it. Psychological testing showed marked selective deficits in some visual spatial tasks notably constructional tasks, visual and tactual block design and tests of personal and spatial orientation. No impairment was found with language, in fact he was exceptionally efficient at verbal learning and memory tasks.

Present condition: Visual fields: right eye normal and a small area of loss in the temporal half field of the left eye. Neurological examination: very little, if any, left sided weakness of limbs but very marked sensory changes including no two point discrimination threshold in fingers, astereognosis, tactile inattention to grip in hand and foot and very defective localisation. CT scan showed a bullet lying in the right

frontal region with extensive damage in the right frontal lobe and extending posteriorly to involve the right motor and parietal cortex. The damage was particularly severe in the upper right parietal region.

11.HS This patient was injured by schrapnel in March 1943, at the age of 20 years, receiving a penetrating wound with indriven bone fragments in the left parietal region associated with loss of consciousness for a few minutes. He was operated on within the next two weeks (details not available). During July 1943 he complained of headaches and dizziness. X-ray, at this time, showed metallic fragments in the scalp with bone fragments around the defect. Neurological examination in May 1944 was normal. The patient reported occasional major epileptic attacks which had begun in December 1943, preceeded by an inability to speak, an unpleasant smell, headache and a peculiar feeling in the stomach. Repeat X-ray in 1953 revealed opaque foreign bodies in the left posterior parietal region and scalp, and a defect in the left parietal bone. At follow-up in 1965 the patient reported headaches, occasional dizziness and difficulty in concentration. Neurological examination was again normal. Psychological tesing showed a slight selective verbal deficit affecting vocabulary, spelling and arithmetic and a very slight impairment in drawing and construction. On admission in 1975 the pattern of performance was unchanged though in addition there were suggestions of a non-verbal memory impairment and significant difficulty with reading, spelling and right/left orientation. The findings were similar in 1980.

Present condition: Full fields both eyes. Neurological examination showed no weakness, reflex change or sensory loss. CT scan showed two large and other fragments of metal in the left upper parietal region associated with destruction of the cortex and slight dilatation of the left lateral ventricle posteriorly.

12.AS At the age of 26 years, in July 1944, this patient received a penetrating wound in the left temporal region with cerebral extrusion. When examined 24 hours later he was found to have a complete right homonymous hemianopia, marked dyslexia and nominal aphasia. X-ray showed an indriven fracture in the left posterior part of the squamous temporal with bone fragments indriven to a depth of nearly four centimetres and a m.f.b. indriven backwards and inwards to a depth of five centimetres. The injury appeared to be transventricular. Thirty-six hours after injury the wound was debrided, 5 c.c.s of pulped brain and twenty small bone chips were removed but the left occipital m.f.b. was left in situ. Post-operative X-ray revealed an operative bone defect at the site of injury, the m.f.b. remaining, but no evidence of residual bone fragments. He steadily improved and by October 1944 had only a right inferior quadrant defect and slight dyslexia. On admission in 1964 the field defect was still present. With psychological testing the only selective impairment was a slight residual aphasia apparent in reading and writing. At this time the patient reported that since his injury he could not read so fast, was less accurate on simple mathematical problems and his short term memory was not so good. Neurological and psychological follow-ups in 1969 and 1975 reported no change with the exception that psychological testing in 1975 showed evidence of a specific verbal memory deficit.

Present condition: Visual fields showed a right lower quadrantic defect. On neurological examination there were no abnormal signs. CT scan revealed a large metallic fragment in the left occipital lobe associated with moderate dilatation of the ventricular system and particular dilatation of the left lateral ventricles posteriorly. The cortex appeared reasonably normal apart from the left temporal lobe where the missile entered the skull. This showed considerable distortion of the white matter and the Sylvian fissure.

13.CS This patient received a penetrating wound in the left parieto-occipital area in July 1944, at the age of 28 years. Two days later the wound was excised and brain pulp sucked out. Bruising of adjacent occipital cortex was noted. The patient was subsequently drowsy and restless for five days with sensory aphasia and gross loss of position sense in the right arm. A cerebral absess was suspected and the old wound was therefore reopened. An intracerebral clot was removed (the findings being consisitent with thrombophlebitis) and a right occipital burr hole made without opening the dura. Post-operative X-ray showed a small depressed fracture in the left anterior parietal region and from this a fissure ran forwards and downwards across the parietal bone to end in the anterior part of the parieto-temporal region. In October 1944 the patient was complaining of headaches, poor concentration and an inability to remember names. On neurological examination there was a right lower quadrant field defect and a right homonomous hemianopic attention defect, but no motor or sensory loss. He showed some receptive and expressive dysphasia and impairment of spatial perception. It was also thought that his memory and learning capacity were impaired for a man whose pre-traumatic intelligence was above average. A tantalum plate was inserted over the skull defect in November 1946 at which time his right hand was normal but he was undergoing speech therapy. In December 1947 he was readmitted due to the onset of fits. On examination visual fields were normal but there was slight weakness, slow postural change and impaired two point discrimination in the right hand. At follow-up in 1969 motor and sensory systems were normal and visual fields full but there was a visual localisation difficulty on the right side. The findings were the same in 1979. Psychological testing was carried out in 1964, 1965 and 1979, the pattern of results being essentially the same on each occasion. General ability, memory and language skills were unimpaired but he showed difficulty with constructional tasks and locomotor route finding.

Present condition: Full visual fields. On neurological examination there was no weakness, reflex change or sensory loss. CT scan: no information obtained at level of plate but there was evidence of left parieto-occip-ital damage on the slice below.

14.WM In October 1944, at the age of 21 years, this patient was hit by mortar shrapnel and obtained a penetrating wound in the left parieto-occipital region just to the left of the midline, associated with loss of consciousness for about five minutes. Preoperative X-ray showed a penetrating injury of the posterior part of the left parietal bone with bone fragments indriven to a depth of three centimetres. Thirty hours after injury the wound was excised, necrosed tissue sucked out and eight bone chips removed. Two small tracks were noted, one anteriorly passing

downwards, forwards and slightly medially for about three centimetres and the other passing downwards and backwards for two centimetres. Postoperative X-ray showed a defect at the site of injury but no remaining bone fragments. On neurological examination there was constriction of the right homonymous field, a minimal right facial weakness and reduced power in the right hand. He also had dysgraphia, slight dyslexia and right/left confusion. He steadily improved and at discharge in January 1945, neurologically, there was a total absence of signs of brain damage but psychiatric asessment showed a degree of intellectual loss and a fairly severe verbal memory impairment. Psychological follow-up in October 1949 reported residual dysgraphia and right/left disorientation. The patient at this time complained of difficulty in finding words and explaining his opinions. Reassessed in 1964 he showed a mild residual dysphasic impairment and mild dyscalculia. On readmission in 1975 neurological examination was normal but psychological testing showed evidence of a pronounced verbal memory deficit, despite well preserved non-verbal memory skills, and difficulty identifying right and left. There was no clinical evidence of dysphasia. This perfomance pattern was unchanged in 1980 when there was still a very marked verbal memory impairment.

Present condition: Full visual fields. Neurologically there were no focal signs. CT scan showed left parietal damage close to the convexity.

15.TC This patient received a penetrating wound to the left parietal area in August 1944. The wound was debrided two days later; brain pulp and about twenty bone chips were removed. Post-operatively he had a right homonymous hemianopia, right hemiparesis and dysphasia. Within two weeks his speech had improved, he could read and write slowly and his hemiparesis was recovering. He complained of focal fits involving twitching of the right leg or right hand without loss of consciousness. Psychological testing nine months later showed him to be retarded on all tests with poor memory and learning capacity, dyscalculia and much imparied visual imagery. At follow-up in 1964 he obtained average scores in intelligence tests but showed slight generalised intellectual impairment and expressive dysphasia. He also had difficulty with tests of arithmetic and construction.

Present condition: Visual field full on left but the right showed slight constriction of all isoptres. On neurological examination his motor ability was probably normal but there were considerable sensory changes with tactile extinction of the right foot.

16.GA At the age if 19 years, in 1944, this patient was hit by mortar fragments and received a left occipital penetrating injury. The wound was excised two days later with removal of three small metallic foreign bodies. The dura was intact and there was no evidence of brain damage. On examination six weeks later he had a right peripheral hemianopia and a tiny right paracentral scotoma in the left eye but no other C.N.S. signs. At follow-up in 1964 his visual fields were full and motor and sensory testing was normal. Detailed psychological examination showed no generalised or selective impairment.

Present condition: Fields full. Right ankle jerk increased compared to

left but otherwise no abnormal signs. CT scan showed evidence of a gun shot wound in the left occipital region with severe atrophy of the left cerebellum and a remaining collection of fragments in the same region.

17.GN At the age of 31 years, in January 1945, this patient received a tangential right parieto-temporal injury with indriven bone fragments and protruding brain tissue. He was aware of loss of power and sensation in the left arm. At operation twenty one hours later the wound was excised with removal of numerous bone fragments and the brain tract sucked clean. Two weeks later he was found to have a left hemiparesis with left hemisensory loss but no facial weakness, visual symptoms or speech difficulty. However, some dysphasic elements were detected during psychological examination two years later and motor aphasia was noted between 1946 and 1967. He made a gradual recovery and in September 1946 underwent a tantalum plate repair. At follow-up in 1968 he still had a moderately severe left hemiparesis with a spastic left arm. Psychological testing revealed slight residual dysphasic symptoms with hesitant reading, spelling errors and word finding difficulty, raising the possibility of bilateral speech representation.

Present condition: Full visual fields. Neurological examination showed a left hemiparesis with severe sensory loss and tactile inattention.

18.TR At the age of 23 years, in April 1945, this patient was hit by penetrating shell fragments in the left parieto-temporal region, with loss of brain tissue. The wound was excised 16 hours after injury revealing a torn dura. Depressed bone fragments and lacerated brain were removed. Post-operatively his speech was slow and slurred and there was slight weakness of the right side of his face. Nine months after injury he received a tantalum repair (which was later removed in 1955). At this time it was noted that he had mild motor and sensory dysfunction involving the right arm and leg, and a very slight residual speech defect. At follow-up in 1968 he had a right inferior quadrantic hemianopia but no right sided weakness or sensory loss. Psychological testing showed no gross impairment but some suggestion of a visual perceptual deficit. In 1979 the findings remained he same except for an added difficulty with verbal memory.

Present condition: Visual fields showed a right homonomous inferior quadrantanopia. Neurologically, there were no abnormal signs. CT scan revealed a bone defect in the left parieto-temporal region and extensive destruction and gliosis of the parietal region with dilatation of the left lateral ventricle mainly posteriorly.

19.AM This patient received a penetrating injury to the left occipital region in April 1945 at the age of 19 years. Four days later the wound was excised revealing lacerated brain tissue and a torn dura. Pulped brain, blood clots and numerous bone fragments were removed. One week post-operatively he had a right homonomous hemianopia and slight weakness of the right arm. Neurological follow-up in 1968 revealed only the right homnomous defect; motor and sensory systems were normal. Psychological testing at this time indicated a residual verbal impairment but no firm

evidence of a visual spatial defect.

Present condition: A complete right hemianopia. No abnormal signs in the limbs.

20.EW At the age of 24 years, in October 1944, this patient was wounded by mortar bomb fragments in the left parieto-temporal region. Two days later the wound was excised involving a burr hole and removal of depressed bone, a large subdural haematoma and an intacerebral clot. Immediately post-operatively he had a slight left hemiparesis (suggesting that the penetrating missile could have crossed the midline) and a marked nominal aphasia but both these findings had resolved one week later. At neurological follow-up in 1967 there was no evidence of any paresis but psychological assessment showed indications of a verbal memory impairment and a slight residual dysphasia. In contrast, scores on non-verbal tasks were average. Psychological follow-up in 1980 showed similar difficulties with verbal material.

Present condition: Full visual fields. Neurological examination revealed no abnormality. CT scan showed left temporo-parietal damage with a vault defect due to an old gunshot wound.

21.RG In January, 1945, at the age of 24 years, this patient was wounded in the right anterior temporal region. Operation, 32 hours later, revealed a large area of ragged, lacerated brain, passing down to the base just in front of the ear. Many bone fragment were removed. Upon regaining consciousness he had a right sided facial weakness, deafness in the right ear, a left homonymous hemianopia and sensory blunting of the left side. He developed occasional epileptic attacks without particular preceding auras; these ceased in 1948. At neurological follow-up in 1967 his redidual defects consisted of a slight right 7th nerve palsy, bilateral deafness, mild left sided sensory loss and an incomplete left hemianopia. Psychological examination revealed a fairly marked deficit in certain visual spatial tasks and the possibility of a mild impairment in language. Both neurological and psychological findings were similar in 1970. In 1980 he still had some difficulty with visual perceptual tasks that could not be ascribed entirely to the visual field defect.

Present condition: Visual fields showed a left homonomous upper quadrantanopia. On neurological examination there was slight blunting to pin prick in the left foot and absent vibration sense in both legs below the knees. CT scan revealed a right parietal defect due to gunshot injury. There was a large irregular gliosis in the right parietal temporal and occipital region.

22.JT At the age of 21 years, in November 1944, this patient received a penetrating wound in the right parieto-occipital region causing considerable protrusion of brain tissue. At operation 24 hours later the bone defect was enlarged (10 by 5 cms) and bone fragments and brain debris removed. Two weeks post-operatively he was mentally "much retarded" with poor concentration. (Psychological assessment regarded him as having been of low pre-traumatic intelligence). He had a complete left

homonomous hemianopia but no motor or sensory signs. X ray showed two remaining indriven bone chips approximately 3 cms from the surface. His skull defect was plated in 1951. Neurological follow-up in 1967 revealed a left homonomous hemianopia but no evidence of aphasia or sensori-motor deficit. Psychological examination showed no indication of generalised intellectual loss or selective deficits (but detailed testing was not attempted in view of the gross visual handicap and modest intellectual endowment.)

Present condition: Both eyes showed a left homonomous hemianopia with, in addition, the left having a right inferior quadrantanopia and the right eye showing a partial right lower quadrantanopia. Neurologically there were no focal signs in the limbs. CT scan revealed evidence of cerebral damage in the right parieto-occipital region and minor changes in the left occipital cortex.

23.RT At the age of 24 years, in July 1944, this patient received a bullet wound to the right occipital region. Operation, 24 hours later, revealed a tiny entrance wound with the bullet lying beneath it, extending forwards to the right. The skull was fractured causing a bony defect 6 x 4 cms. On excision the dura was found to be torn with extruding blood clot and brain pulp. The bullet and several bone chips were removed. Neurological examination five days after injury revealed a left homonymous hemianopia but no motor or sensory deficits. At follow-up in 1964 the patient remained unchanged neurologically. Skull X-ray showed a right parieto-occipital defect. On psychological testing there was difficulty in tasks involving visuospatial skills but there was no impairment in verbal or memory functions. Repeat neurological follow-ups in 1965 and 1980 found his condition unchanged.

Present condition: Visual fields showed a left homonomous hemianopia. Neurologically, there were no abnormal signs. CT scan revealed extensive destruction in the right occipital region without metal fragments. The ventricular system was virtually normal apart from some dilatation of the right occipital horn.

24.LH In April 1944, at the age of 30 years, this patient was wounded in Burma by mortar shell fragments causing a penetrating injury to the right occipital region. (He was operated on within days but details are not available). After evacuation to the U.K. in December '44 he was found to have a general constriction of the visual fields with a left homonomous hemianopia. There was no weakness, ataxia or sensory deficit. Skull X-ray showed an operative defect 3 cms in diameter in the right parieto-occipital region. Tachistoscopy, performed in 1951, reported that the field loss indicated complete damage to the right occipital cortex and damage also to the left occipital cortex anteriorly. Neurological follow-up in 1967 showed a left homonomous hemianopia and a right lower quadrantanopia but sensory and motor testing was essentially normal. The patient reported having occasional disturbances of vision associated with headache but no blackouts or convulsions. On psychological testing he had a low score in immediate and delayed recall but this was thought to be due to his severe deafness. He had marked difficulty in visual perception tasks but there was no impairment in personal or spatial orientation.

Present condition: Visual fields showed a left homonomous hemianopia. Neurologically there were no abnormal signs except deafness in the right ear. CT scan revealed extensive damage in the right parietal and temporal regions extending into the occipital cortex.